Chapter 4
YELLOWFIN SOLE

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Executive Summary

The following changes have been made to this assessment relative to the November 2004 SAFE:

Changes to the input data

1) 2004 fishery age composition.
2) 2004 survey age composition.
3) 2005 trawl survey biomass point estimate and standard error.
4) Estimate of the discarded and retained portions of the 2004 catch.
5) Estimate of total catch through 3 September 2005.

Assessment results

1) The projected age 2+ total biomass for 2006 is 1,682,200 t.
2) The projected female spawning biomass for 2006 is 484,800 t.
3) The recommended 2006 ABC is 121,400 t based on an $F_{40\%}$ (0.11) harvest level.
4) The 2006 overfishing level is 144,000 t based on an $F_{35\%}$ (0.14) harvest level.

The survey biomass estimate of 2,767,800 t used in this assessment was preliminary and the estimate was revised to 2,823,500 t on October 14, 2005. The revised estimate will be used in the SAFE for next year.

Summary

	2005 Assessment Recommendations for 2006 harvest	2004 Assessment Recommendations for 2005 harvest
Total biomass	1,682,200 t	1,557,900 t
ABC	121,400 t	124,300 t
Overfishing yield	144,000 t	147,500 t
F_{ABC}	$F_{0.40} = 0.11$	$F_{0.40} = 0.11$
$F_{overfishing}$	$F_{0.35} = 0.14$	$F_{0.35} = 0.14$
$B_{40\%}$	412,000 t	387,600 t
$B_{35\%}$	360,000 t	341,000 t

SSC Comments from December 2004

"As part of the continuing effort to incorporate ecosystem effects, detailed examination of stock recruit relationships were made for several flatfish stocks, specifically: flathead sole, northern rock sole, arrowtooth flounder, Alaska plaice and yellowfin sole. As part of these explorations, the assessment authors fit separate

stock recruitment models to subsets of the data to examine the possible effect of a 1989 climate regime shift. For yellowfin sole, the spawner-recruit analysis focused on the 1976-77 regime shift. If a reliable stock-recruitment relationship is found, a stock could be considered for management under Tier 1. In all cases, significantly different stock recruitment relationships were found for subsets of the data. These results appear to illustrate the non-stationarity of stock-recruitment relationships over time for Bering sea flatfish stocks and provide the basis for questioning whether a single stock-recruitment curve adequately captures the dynamics of the stock. These stocks are excellent candidates for ongoing harvest policy investigations in a Management Strategy Evaluation framework, and the SSC looks forward to results from these analyses."

A Management Strategy Evaluation model has been constructed and initial runs made using yellowfin sole as a candidate species. The model is still being subjected to some refinement and we are considering what range of life history characteristics to test and what are the acceptable time-scales of climate regimes to consider. In its present form the model is a single-species evaluation of future catch and biomass but needs to further developed to be a representation of future multi-species bycatch. We hope to present results in 2006.

Introduction

The yellowfin sole (Limanda aspera) is one of the most abundant flatfish species in the eastern Bering Sea (EBS) and is the target of the largest flatfish fishery in the United States. They inhabit the EBS shelf and are considered one stock. Abundance in the Aleutian Islands region is negligible.

Yellowfin sole are distributed in North American waters from off British Columbia, Canada, (approx. lat. 49° N) to the Chukchi Sea (about lat. 70° N) and south along the Asian coast to about lat. 35° N off the South Korean coast in the Sea of Japan. Adults exhibit a benthic lifestyle and occupy separate winter, spawning and summertime feeding distributions on the eastern Bering Sea shelf. From over-winter grounds near the shelf margins, adults begin a migration onto the inner shelf in April or early May each year for spawning and feeding. The directed fishery typically occurs from spring through December.

Catch History

Yellowfin sole have annually been caught with bottom trawls on the Bering Sea shelf since the fishery began in 1954 and were overexploited by foreign fisheries in 1959-62 when catches averaged 404,000 t annually (Fig. 4.1). As a result of reduced stock abundance, catches declined to an annual average of 117,800 t from 1963-71 and further declined to an annual average of 50,700 t from 1972-77. The lower yield in this latter period was partially due to the discontinuation of the U.S.S.R. fishery. In the early 1980s, after the stock condition had improved, catches again increased reaching a recent peak of over 227,000 t in 1985.

During the 1980s, there was also a major transition in the characteristics of the fishery. Yellowfin sole were traditionally taken exclusively by foreign fisheries and these fisheries continued to dominate through 1984. However, U.S. fisheries developed rapidly during the 1980s in the form of joint ventures, and during the last half of the decade began to dominate and then take all of the catch as the foreign fisheries were phased out of the EBS. Since 1990, only domestic harvesting and processing has occurred. The annual total catch (t) since implementation of the MFCMA in 1977 are shown in Table 4.1.

The 1997 catch of 181,389 t was the largest since the fishery became completely domestic but has since been at lower levels averaging 78,000 t from 1998-2005. As of 3 September, the 2005 catch totaled 90,625 t, the highest annual catch in the past 7 years. The fishery caught 2/3 of the annual total during March and April, primarily from areas 514 and 524, and was finished on August 24 when the TAC was attained. The size composition of the 2005 catch for both males and females, from observer sampling, are shown in Figure 4.1 and the locations where yellowfin sole were caught in 2005, by month, are shown in the Appendix figures.

Harvesting events requiring regulatory actions in 2005 were as follows: The directed fishery was closed in BSAI Zone 1 on March 14 to prevent exceeding the red king crab bycatch allowance and retention of yellowfin sole was prohibited on May 19 due to the attainment of the TAC. On July 25, 6,800 t of yellowfin sole TAC reserve was released to supplement the TAC which prolonged the fishery until August 24 at which time yellowfin sole were no longer allowed to be retained in BSAI fisheries.

The catch information presented above also includes yellowfin sole which were discarded in domestic fisheries since their beginning in 1987. Annual discard estimates are calculated from at-sea sampling for 1987-2004 are shown in Table 4.2. The rate of discard has ranged from a low of 14% of the total catch in 2001 to 30% in 1992. The trend has been toward fuller retention of the catch in recent years Discarding primarily occurs in the yellowfin sole directed fishery, with lesser amounts in the Pacific cod, rock sole, flathead sole, and other flatfish fisheries (Table 4.3).

Data

The data used in this assessment include estimates of total catch, bottom trawl survey biomass estimates and their attendant 95% confidence intervals, catch-at-age from the fishery and population age composition estimates from the bottom trawl survey. Weight-at-age and proportion mature-at-age are also available from studies conducted during the bottom trawl surveys.

Fishery Catch and Catch-at-Age

This assessment uses fishery catch data from 1955- September 3 2005 (Table 4.1) and fishery catch-at-age (numbers) from 1964-2004 (Table 4.4, 1977-2004).

Survey Biomass Estimates and Population Age Composition Estimates

Biomass estimates for yellowfin sole from the annual bottom trawl survey on the eastern Bering Sea shelf are shown in Table 4.5. Estimates are given separately for unexploited ages (less than age 7) and exploited ages (ages 7 and older) except for 2005 where age data are not yet available. The data show a doubling of biomass between 1975 and 1979 with a further increase to over 2.3 million t in 1981 for the exploitable portion of the population. Survey abundance estimates fluctuated erratically from 1981 to 1990 with biomass ranging from as high as 3.5 million t in 1983 to as low as 1.9 million t in 1986. Biomass estimates since 1990 indicate an even trend at high levels of abundance for yellowfin sole, with the exception of the results from the 1999 and 2000 summer surveys, which were at lower levels. The last 5 surveys have estimated an increase each year.

Indices of relative abundance available from AFSC surveys have also shown a major increase in the abundance of yellowfin sole during the late 1970s increasing from 21 kg/ha in 1975 to 51 kg/ha in 1981 (Fig. 4.2, Bakkala and Wilderbuer 1990). These increases have also been documented through Japanese commercial pair trawl data and catch-at-age modeling in past assessments (Bakkala and Wilderbuer 1990).

Since 1981, the survey CPUEs have fluctuated widely. For example, they increased from 51 kg/ha in 1981 to 84 kg/ha in 1983 and then declined sharply to 49 kg/ha in 1985. They continued to fluctuate from 1986-90, although with less amplitude (Fig 4.2). From 1990-1998, the estimated CPUE was relatively stable but have declined the past two years. Fluctuations of the magnitude shown between 1980 and 1990 and again between 1998 and 1999 are unreasonable considering the combined elements of slow growth and long life span of yellowfin sole and low exploitation rate, characteristics which should produce more gradual changes in abundance.

Variability of yellowfin sole survey abundance estimates (Fig. 4.3) is in part due to the availability of yellowfin sole to the survey area (Nichol, 1998). Yellowfin sole are known to undergo annual migrations from wintering areas off the shelf-slope break to nearshore waters where they spawn throughout the spring and summer months (Nichol, 1995; Wakabayashi, 1989; Wilderbuer et al., 1992). Exploratory survey sampling in coastal waters of the eastern Bering Sea indicate that yellowfin sole concentrations can be greater in these shallower areas not covered by the standard AFSC survey. Commercial bottom trawlers have commonly found high concentrations of yellowfin sole in areas such as near Togiak Bay (Low and Narita, 1990) and in more recent years from Kuskokwim Bay to just south of Nunivak Island. The coastline areas are sufficiently large enough to offer a substantial refuge for yellowfin sole from the current survey.

Over the past 15 years survey biomass estimates for yellowfin sole have shown a positive correlation with shelf bottom temperatures (Nichol, 1998); estimates have been low during cold years. The 1999 survey, which was conducted in exceptionally cold waters, indicated a biomass estimate that was unrealistically low. The bottom temperatures during the 2000 survey were much warmer than in 1999, and the biomass increased, but still did not approach estimates from earlier years. Average bottom temperature and biomass both increased again in 2001 – 2003, with the 2003 value the highest observed over the 22 year time series. Given that both 1999 and 2000 surveys were conducted two weeks earlier than previous surveys, it is possible that the time difference may also have affected the availability of yellowfin sole to the survey. If, for example, the timing of peak yellowfin sole spawning in nearshore waters corresponded to the time of the survey, a greater proportion of the population would be unavailable to the standard survey area.

We propose two possible reasons why survey biomass estimates are lower during years when bottom temperatures are low. First, catchability may be lower because yellowfin sole may be less active when temperatures are low. Less active fish may be less susceptible to herding, and escapement under the footrope of survey gear may increase if fish are less active. Secondly, bottom temperatures may influence the timing of the inshore spawning migrations of yellowfin sole and therefore affect their availability to the survey area. Because yellowfin sole spawning grounds include nearshore areas outside the survey area, availability of fish within the survey area can vary with the timing of this migration and the timing of the survey. As was the case in 2000, greater than average catches along the survey border outside of Kuskowkim bay may indicate that a significant portion of the biomass lies outside this border (Fig 4.4).

Yellowfin sole population numbers-at-age estimated from the annual bottom trawl surveys are shown in Table 4.6.

Length and Weight-at-Age and Maturity-at-Age

Parameters of the von Bertalanffy growth curve for yellowfin sole from 12 years of combined data have been estimated as follows:

age range	L_{inf} (cm)	K	t_0
3-26	35.8	0.147	0.47

Mean lengths and weights at age of yellowfin sole based on 12 years (1979-90) of data from AFSC surveys and the length (cm) – weight (g) relationship (W = 0.0097217 * L ** 3.0564) are shown in Table 4.7. Changes in length and weight at age over time has been documented for Bering Sea rock sole (Walters and Wilderbuer 2000) and Bering Sea and Gulf of Alaska Pacific halibut (Clark et al 1999). We examined our assumption of time invariant growth in length and weight of yellowfin sole by comparing the weight and length at age from fish collected during the 1987, 1994, 1999, 2000 and 2001 surveys (Fig. 4.5). Over the age range of 4 to 14 years (fish ageing > 14 years has more error and smaller sample sizes) there are only small differences in length and weight at age from 1987 to 2001. Largest annual differences in weight at age were found in 1999 (a cold year) which were not present in the same cohorts in 2001 (a warmer year). These differences seem to be more related to annual metabolic rate than a shift in population-wide growth. Based on these findings, we concluded that use of a single weight at age vector was justified for this assessment.

Maturity information collected from yellowfin sole females during the 1992 and 1993 eastern Bering Sea trawl surveys is used in this assessment (Table 4.8). Nichol (1994) estimated the age of 50% maturity at 10.5 years based on the histological examination of 639 ovaries. In the case of most north Pacific flatfish species, including yellowfin sole, sexual maturity occurs well after the age of entry into the fishery. Yellowfin sole are 90% selected to the fishery by age 11 but females have been found to be only 50% mature at this age.

Analytic Approach

Model Structure

The abundance, mortality, recruitment and selectivity of yellowfin sole were assessed with a stock assessment model using the AD Model builder language (Ianelli and Fournier 1998). The conceptual model is a separable catch-age analysis that uses survey estimates of biomass and age composition as auxiliary information (Fournier and Archibald 1982). The assessment model simulates the dynamics of the population and compares the expected values of the population characteristics to the characteristics observed from surveys and fishery sampling programs. This is accomplished by the simultaneous estimation of the parameters in the model using the maximum likelihood estimation procedure. The fit of the simulated values to the observable characteristics is optimized by maximizing a log(likelihood) function given some distributional assumptions about the observed data.

The suite of parameters estimated by the model are classified by three likelihood components:

Data component	**Distributional assumption**
Trawl fishery catch-at-age	Multinomial
Trawl survey population age composition	Multinomial
Trawl survey biomass estimates and S.E.	Log normal

The total log likelihood is the sum of the likelihoods for each data component (Table 4.9). The likelihood components may be weighted by an emphasis factor, however, equal emphasis was placed on fitting each likelihood component in the yellowfin sole assessment except for the catch. The AD Model Builder software fits the data components using automatic differentiation (Griewank and Corliss 1991) software developed as a set of libraries (AUTODIFF C++ library). Table 4.9 presents the key equations used to model the yellowfin sole population dynamics in the Bering Sea and Table 4.10 provides a description of the variables used in Table 4.9.

Sharp increases in trawl survey abundance estimates for most species of Bering Sea flatfish between 1981 and 1982 indicate that the 83-112 trawl was more efficient for capturing these species than the 400-mesh eastern trawl used in 1975, and 1979-81. Allowing the model to tune to these early survey estimates would most likely underestimate the true pre-1982 biomass, thus exaggerating the degree to which biomass increased during that period. Although this underestimate would have little effect on the estimate of current yellowfin sole biomass, it would affect the spawner and recruitment estimates for the time-series. Hence, the pre-1982 survey biomass estimates were omitted from the analysis.

The model of yellowfin sole population dynamics was evaluated with respect to the observations of the time-series of survey and fishery age compositions and the survey biomass trend since 1982.

Parameters Estimated Independently

Natural mortality (M) was initially estimated by a least squares analysis where catch-at-age data were fitted to Japanese pair trawl effort data while varying the catchability coefficient (q) and M simultaneously. The best fit to the data (the point where the residual variance was minimized) produced a M value of 0.12 (Bakkala and Wespestad 1984). This was also the value which provided the best fit to the observable population characteristics when M was profiled over a range of values in the stock assessment model using data up to 1992 (Wilderbuer 1992). Allowing M to be estimated as a free parameter, given the current assessment data, has the undesirable result of very low values of M, high estimates of q and low estimates of biomass, which are not credible. Thus, a natural mortality value of 0.12 is used in this assessment.

Yellowfin sole maturity schedules were estimated from in situ observations as discussed in a previous section (Table 4.8).

Parameters Estimated Conditionally

The parameters estimated by the model are presented below:

Fishing mortality	Selectivity	Survey catchability	Year class strength	Spawner-recruit	Total
52	4	2	71	2	131

The increase in the number of parameters estimated in this assessment compared to last year can be accounted for by the input of another year of fishery data and the entry of another year class into the observed population.

Year class strengths

The population simulation specifies the numbers-at-age in the beginning year of the simulation, the number of recruits in each subsequent year, and the survival rate for each cohort as it moves through the population over time using the population dynamics equations given in Table 4.9.

Selectivity

Fishery and survey selectivity was modeled in this assessment using the two parameter formulation of the logistic function, as shown in Table 4.9. The model was run with an asymptotic selectivity curve for the older fish in the fishery and survey, but still was allowed to estimate the shape of the logistic curve for young fish. The oldest year classes in the surveys and fisheries were truncated at 20 and allowed to accumulate into the age category 20+ years.

Fishing Mortality

The fishing mortality rates (F) for each age and year are calculated to approximate the catch weight by solving for F while still allowing for observation error in catch measurement. A large emphasis was placed on the catch likelihood component.

Survey Catchability

A past assessment (Wilderbuer and Nichol 2001) first examined the relationship between estimates of survey biomass and bottom water temperature. To better understand how water temperature may affect the catchability of yellowfin sole to the survey trawl, catchability was estimated for each year in the stock assessment model as:

$$q = e^{\alpha + \beta T}$$

where q is catchability, T is the average annual bottom water temperature anomaly at survey stations less than 100 m, and -α and β are parameters estimated by the model. The result of the nonlinear fit to bottom temperature vs. estimated q is shown in Figure 4.6.

Spawner-Recruit Estimation

Annual recruitment estimates were constrained to fit a Ricker (1958) form of the stock recruitment relationship as follows:

$$R = \alpha S e^{-\beta S}$$

where R is age 1 recruitment, S is female spawning biomass (t) the previous year, and α and β are parameters estimated by the model. The spawner-recruit fitting is estimated in a later phase after initial estimates of survival, numbers-at-age and selectivity are obtained.

Model Evaluation

Modeling survey catchability as a nonlinear function of bottom water temperature at stations less than 100 m produces an estimate of survey catchability greater than 1. This value is consistent with supporting evidence from experiments examining the bridle efficiency of the Bering Sea survey trawl which indicate that yellowfin sole are herded into the trawl path from an area between the wing tips of the net and the point where the bridles contact the seafloor (Somerton and Munro 2001). These experiments suggest that the survey trawl catchability is greater than 1.0. The likelihood profile of q from the model indicated a small variance with a narrow range of likely values with a low probability of q being equal to the value of 1.0 (Wilderbuer and Nichol 2003). The model of choice for this assessment is the model which estimates an annual q by considering average bottom water temperature because it is consistent with 1) our knowledge of flatfish behavior to the survey trawl gained from herding experiments and 2) our hypothesis of the timing of the survey relative to the temperature dependent timing of the annual spawning migration to nearshore areas which are outside of the survey area.

Model Results

Fishing Mortality and Selectivity

The assessment model estimates of the annual fishing mortality on fully selected ages are given in Table 4.11. The full-selection F has averaged 0.1 over the period of 1978-2004 with a maximum of 0.13 in 1997 and a minimum in 2001 at 0.05. Selectivities estimated by the model (Table 4.12, Figure 4.7) indicate that yellowfin sole are 50% selected by the fishery at age 9 and nearly fully selected by age 13.

Abundance Trend

The model estimates q at an average value of 1.27 for the period 1982-2005 which results in the model estimate of the 2005 total biomass at 1,705,100 t (Table 4.13). Model results indicate that yellowfin sole total biomass (age 2+) was at low levels during most of the 1960s and early 1970s (600,000-800,000 t) after a period of high exploitation (Table 4.13, Figure 4.7, bottom left panel). Sustained above average recruitment from 1967-76 combined with light exploitation resulted in a biomass increase to a peak of 2.6 million t by 1985. The population biomass has since been in a slow decline as the strong 1981 and 1983 year-classes have passed through the population with only the 1991 and 1995 year classes at levels observed during the 1970s. Over the past twenty years stock biomass has declined 800,000 t since the peak biomass observed in 1985 (65% of the peak level).

The female spawning biomass has also steadily declined since the peak in 1985, with a 2005 estimate of 538,000 t (25% decline). This level of spawning biomass is about 130% of the $B_{40\%}$ level (Fig. 4.8). The model estimate of yellowfin sole population numbers at age for all years is shown in Table 4.14 and the resulting fit to the observed fishery and survey age compositions input into the model are shown in the Appendix. The fit to the trawl survey biomass estimates are shown in Figure 4.7. Allowing q to be correlated with annual bottom temperature provides a better fit to the bottom trawl survey estimates.

Both the trawl survey and the stock assessment model indicate that the yellowfin sole resource slowly increased during the 1970s and early 1980s to a peak level during the mid-1980s and that the resource has been in a slow, consistent decline since then (Figure 4.7). Above average recruitment from the 1991 and 1995 year-classes is expected to maintain the abundance of yellowfin sole at a level above B_{40} in the near future. The stock assessment projection model (later section) indicates a slow increase in female spawning biomass in the near future if the fishing mortality rate continues at the same level as the average of the past 5 years.

Total Biomass

The stock assessment model estimate of total biomass (begin year population numbers multiplied by mid-year weight at age) is used to recommend the ABC for 2006. Including the 2005 reported catch through 3 September (including discards), the model projects the total biomass for 2006 at **1,682,200 t**.

Recruitment Trends

The primary reason for the sustained increase in abundance of yellowfin sole during the 1970s and early 1980s was the recruitment of a series of stronger than average year classes spawned in 1967-76 (Figure 4.9 and Table 4.15). The 1981 year class was the strongest observed (and estimated) during the 46 year period analyzed and the 1983 year class was also very strong. Survey age composition estimates and the assessment model also estimate that the 1987 and 1988 year classes were average and the 1991 and 1995 year classes are strong. With the exception of these 4 year classes, recruitment from 12 of the last 16 years estimated (since the strong 1983 year-class) has been below the 48 year average, which has caused the population decline. The 1995 year-class are at the maximum of their cohort biomass in 2005 and should contribute to the mature adult reservoir of spawners in future years.

Tier 1 Considerations

The SSC has requested that flatfish assessments which have a lengthy time-series of stock and recruitment estimates explore management under a Tier 1 harvest policy. In the case of yellowfin sole, we have a lengthy time series of 45 years. MSY is an equilibrium concept and its value is dependent on both the spawner-recruit data which we assume represents the equilibrium stock size-recruitment relationship and the model used to fit the data. In the stock assessment model used here, a Ricker form of the stock-recruit relationship was fit to these data and estimates of F_{MSY} and B_{MSY} were calculated, assuming that the fit to the stock-recruitment data points represent the long-term productivity of the stock. However, very different estimates of F_{MSY} and B_{MSY} were obtained, depending on which years of stock-recruitment data points were included in the fitting procedure (Fig. 4.10). When we fit the entire time-series from 1954-1999, we include large recruitments that occurred at a low spawning stock size in the 1960s and early 1970s which indicate a productive stock that is able to replace itself quite well at low stock sizes. Therefore, MSY and F_{MSY} are relatively high values (217,000 t and 0.37, respectively) and B_{MSY} is 208,800 t. If we limit the data to consider only recruitments which occurred after the well-documented regime shift in 1977, much lower values of MSY and F_{MSY} are obtained (150,100 t and 0.22, respectively) and B_{MSY} is 249,800 t.

This calls into concern whether a single fit of stock recruitment time-series data is able to reliably capture the long-term reproductive potential of the yellowfin sole stock. A recent analysis of flatfish recruitment indicates that temporal trends in winter spawning flatfish production in the Eastern Bering Sea are consistent with the hypothesis that decadal scale climate variability influences marine survival during the early life history period (Wilderbuer et al. 2002). Periods of cross-shelf advection for winter spawning flatfish larvae were found to coincide with synchronous above-average recruitment (1980s) whereas periods of weak advection or advection to the west were associated with poor recruitment (1990s). These changes in stock productivity were found to coincide with a decadal scale shift in atmospheric forcing which warrant caution when trying to determine the long-term reproductive potential of this stock.

The aforementioned analysis was performed for rock sole, arrowtooth flounder and flathead sole, species which spawn in the winter in offshore areas and are seemingly reliant upon advection to nursery areas 3-4 months later. In contrast, yellowfin sole are known to spawn in shallow near shore areas of northern Bristol Bay, primarily in May and June, where it would seem that advection would play a diminished role in juvenile survival resulting in less variable recruitment. However, it is evident from Figure 4.9 that the time series of year class strength for yellowfin sole has shifts in production (1956-66, 1967-77, 1984-97). These shifts may be a cause of concern if we assume that the long term productivity is closely related to spawning stock size while ignoring mechanisms governing the variability in production which may correspond to decadal (or longer) shifts in environmental conditions.

Given these concerns, the authors are currently performing a simulation study to determine the appropriateness of applying a harvest strategy from fitting the full time series for a fish stock experiencing temporal changes in reproductive potential due to changing oceanic conditions. For this assessment then, we recommend a continued Tier 3 harvest strategy. Under this harvest strategy, the fishing mortality limit ($F_{0.35}$ = 0.137) is much more conservative than they would be under a Tier 1 harvest strategy (F_{MSY} = 0.37 using all data or F_{MSY} = 0.22 using 1977-2000 data).

Historical Exploitation Rates

Based on results from the stock assessment model, annual exploitation rates of yellowfin sole ranged from 3 to 9% of the total biomass since 1977, and have averaged 7% (Table 4.11).

Acceptable Biological Catch

After increasing during the 1970s and early 1980s, estimates from the stock assessment model indicate the total biomass has been at a slow decline from high levels of stock biomass since the peak in 1985. The estimate of total biomass for 2006 is 1,682,200 t.

The reference fishing mortality rate for yellowfin sole is determined by the amount of population information available (Amendment 56 of the Fishery Management Plan for the groundfish fishery of the Bering Sea/Aleutian Islands). Equilibrium female spawning biomass is calculated by applying the female spawning biomass per recruit resulting from a constant $F_{0.40}$ harvest to an estimate of average equilibrium recruitment. The Alaska Fisheries Science Center policy is to use year classes spawned in 1977 or later to calculate the average equilibrium recruitment if no compelling reason exists to do otherwise. For this assessment we use the time-series of recruitment numbers estimated for 1978-2003 from the stock assessment model to estimate **$B_{0.40}$ = 412,000 t**. The stock assessment projection model estimates the 2006 level of female spawning biomass at 484,800 t (B). Since reliable estimates of B, $B_{0.40}$, $F_{0.40}$, and $F_{0.35}$ exist and $B > B_{0.40}$ (484,800 > 412,000, Figure 4.8), yellowfin sole reference fishing mortality is defined in tier 3a. For the 2006 harvest: $F_{ABC} \leq F_{0.40} = 0.11$ (full selection F values).

Acceptable biological catch is estimated for 2006 by applying the $F_{0.40}$ fishing mortality rate and age-specific fishery selectivities to the projected 2006 estimate of age-specific total biomass as follows:

$$ABC = \sum_{a=a_r}^{a_{nages}} \overline{w}_a n_a \left(1 - e^{-M - Fs_a}\right) \frac{Fs_a}{M + Fs_a}$$

where S_a is the selectivity at age, M in natural mortality, W_a is the mean weight at age, a_r is the age at recruitment to the fishery and n_a is the beginning of the year numbers at age. **This calculation results in a 2006 ABC of 121,400 t**.

Overfishing

The stock assessment analysis must also consider harvest limits, usually described as “overfishing” fishing mortality levels with corresponding yield amounts. Amendment 56 to the BSAI FMP now sets the harvest limit at the $F_{0.35}$ fishing mortality value or the fishing mortality rate which would reduce the spawning biomass per recruit to 35% of its unfished level (for tier 3a). The overfishing fishing mortality value, ABC fishing mortality value and their corresponding yields are given as follows:

Harvest level	F value	2006 Yield
$F_{OFL} = F_{0.35}$	0.136	144,000 t
$F_{ABC} = F_{0.40}$	0.113	121,400 t

Biomass Projections

Status Determination

A standard set of projections is required for each stock managed under Tiers 1, 2, or 3 of Amendment 56. This set of projections encompasses seven harvest scenarios designed to satisfy the requirements of Amendment 56, the National Environmental Policy Act, and the Magnuson-Stevens Fishery Conservation and Management Act (MSFCMA).

For each scenario, the projections begin with the vector of 2005 numbers at age estimated in the assessment. This vector is then projected forward to the beginning of 2006 using the schedules of natural mortality and selectivity described in the assessment and the best available estimate of total (year-end) catch for 2005. In each subsequent year, the fishing mortality rate is prescribed on the basis of the spawning biomass in that year and the respective harvest scenario. In each year, recruitment is drawn from an inverse Gaussian distribution whose parameters consist of maximum likelihood estimates determined from recruitments estimated in the assessment. Spawning biomass is computed in each year based on the time of peak spawning and the maturity and weight schedules described in the assessment. Total catch is assumed to equal the catch associated with the respective harvest scenario in all years. This projection scheme is run 1000 times to obtain distributions of possible future stock sizes, fishing mortality rates, and catches.

Five of the seven standard scenarios will be used in an Environmental Assessment prepared in conjunction with the final SAFE. These five scenarios, which are designed to provide a range of harvest alternatives that are likely to bracket the final TAC for 2006, are as follow ("*max* F_{ABC}" refers to the maximum permissible value of F_{ABC} under Amendment 56):

Scenario 1: In all future years, F is set equal to *max* F_{ABC}. (Rationale: Historically, TAC has been constrained by ABC, so this scenario provides a likely upper limit on future TACs.)

Scenario 2: In all future years, F is set equal to a constant fraction of *max* F_{ABC}, where this fraction is equal to the ratio of the F_{ABC} value for 2006 recommended in the assessment to the *max* F_{ABC} for 2006. (Rationale: When F_{ABC} is set at a value below *max* F_{ABC}, it is often set at the value recommended in the stock assessment.)

Scenario 3: In all future years, F is set equal to 50% of max F_{ABC}. (Rationale: This scenario provides a likely lower bound on F_{ABC} that still allows future harvest rates to be adjusted downward when stocks fall below reference levels.)

Scenario 4: In all future years, F is set equal to the 2001-2005 average F. (Rationale: For some stocks, TAC can be well below ABC, and recent average F may provide a better indicator of F_{TAC} than F_{ABC}.)

Scenario 5: In all future years, F is set equal to zero. (Rationale: In extreme cases, TAC may be set at a level close to zero.)

Two other scenarios are needed to satisfy the MSFCMA's requirement to determine whether a stock is currently in an overfished condition or is approaching an overfished condition. These two scenarios are as follow (for Tier 3 stocks, the MSY level is defined as $B_{35\%}$):

Scenario 6: In all future years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is overfished. If the stock is expected to be above ½ of its MSY level in 2006 and above its MSY level in 2016 under this scenario, then the stock is not overfished.)

Scenario 7: In 2006 and 2007, F is set equal to *max* F_{ABC}, and in all subsequent years, F is set equal to F_{OFL}. (Rationale: This scenario determines whether a stock is approaching an overfished condition. If the stock is expected to be above its MSY level in 2018 under this scenario, then the stock is not approaching an overfished condition.)

Simulation results shown in Table 4.16 and Figure 4.11 indicate that yellowfin are not currently overfished and are not approaching an overfished condition.

Scenario Projections and Two-Year Ahead Overfishing Level

In addition to the seven standard harvest scenarios, Amendments 48/48 to the BSAI and GOA Groundfish Fishery Management Plans require projections of the likely OFL two years into the future. While Scenario 6 gives the best estimate of OFL for 2006, it does not provide the best estimate of OFL for 2007, because the mean 2007 catch under Scenario 6 is predicated on the 2006 catch being equal to the 2006 OFL, whereas the actual 2006 catch will likely be less than the 2006 ABC. Therefore, the projection model was re-run with the 2006 catch fixed equal to the 2005 catch and the 2007 fishing mortality rate fixed at F_{ABC}.

Year	Catch	ABC	OFL
2006	90,600	**121,400**	**144,000**
2007	115,600	**115,200**	**137,100**

Ecosystem Considerations

Ecosystem Effects on the stock

1) Prey availability/abundance trends
Yellowfin sole diet by life stage varies as follows: Larvae consume plankton and algae, early juveniles consume zooplankton, late juvenile stage and adults prey includes bivalves, polychaetes, amphipods, mollusks, euphausids, shrimps, brittle stars, sculpins and miscellaneous crustaceans. Information is not available to assess the abundance trends of the benthic infauna of the Bering Sea shelf. The original description of infaunal distribution and abundance by Haflinger (1981) resulted from sampling conducted in 1975 and 1976 and has not been re-sampled since. The large populations of flatfish which have occupied the middle shelf of the Bering Sea over the past twenty years for summertime feeding do not appear food-limited. These populations have fluctuated due to the variability in recruitment success which suggests that the primary infaunal food source has been at an adequate level to sustain the yellowfin sole resource.

2) Predator population trends
As juveniles, it is well-documented from studies in other parts of the world that flatfish are prey for shrimp species in near shore areas. This has not been reported for Bering Sea yellowfn sole due to a lack of juvenile sampling and collections in near shore areas, but is thought to occur. As late juveniles they have been found in stomachs of Pacific cod and Pacific halibut; mostly on small yellowfin sole ranging from 7 to 25 cm standard length..

Past, present and projected future population trends of these predator species can be found in their respective SAFE chapters in this volume and also from Annual reports compiled by the International Pacific Halibut Commission. Encounters between yellowfin sole and their predators may be limited since their distributions do not completely overlap in space and time.

3) Changes in habitat quality
Changes in the physical environment which may affect yellowfin sole distribution patterns, recruitment success, migration timing and patterns and are catalogued in the Ecosystem Considerations Appendix of this SAFE report. Habitat quality may be enhanced during years of favorable cross-shelf advection (juvenile survival) and warmer bottom water temperatures with reduced ice cover (higher metabolism with more active feeding).

Fishery Effects on the ecosystem

1) The yellowfin sole target fishery contribution to the total bycatch of other non-prohibited species is shown for 1991-2004 in Table 4.17. The yellowfin sole target fishery contribution to the total bycatch of prohibited species is shown for 2003 and 2004 in Table 13 of the Economic SAFE (Appendix C) and is summarized for 2004 as follows:

Prohibited species	Yellowfin sole fishery % of total bycatch
Halibut mortality	14.0
Herring	7.0
Red King crab	41.7
C. bairdi	30.2
Other Tanner crab	71.4
Salmon	< 1

2) Relative to the predator needs in space and time, the yellowfin sole target fishery has a low selectivity for fish between 7-25 cm and therefore has minimal overlap with removals from predation.

3) The target fishery is not perceived to have an effect on the amount of large size target fish in the population due to it’s history of light exploitation (6%) over the past 27 years.

4) Yellowfin sole fishery discards are presented in the Catch History section.

5) It is unknown what effect the fishery has had on yellowfin sole maturity-at-age and fecundity.

6) Analysis of the benthic disturbance from the yellowfin sole fishery is available in the Preliminary draft of the Essential Fish Habitat environmental Impact Statement.

Ecosystem effects on yellowfin sole

Indicator	Observation	Interpretation	Evaluation
Prey availability or abundance trends			
Benthic infauna	Stomach contents	Stable, data limited	Unknown
Predator population trends			
Fish (Pacific cod, halibut, skates)	Stable	Possible increases to rock sole mortality	
Changes in habitat quality			
Temperature regime	Cold years yellowfin sole catchability and herding may decrease, timing of migration may be prolonged	Likely to affect surveyed stock	No concern (dealt with in model)
Winter-spring environmental conditions	Affects pre-recruit survival	Probably a number of factors	Causes natural variability

***Yellowfin sole* effects on ecosystem**

Indicator	Observation	Interpretation	Evaluation
Fishery contribution to bycatch			
Prohibited species	Stable, heavily monitored	Minor contribution to mortality	No concern
Forage (including herring, Atka mackerel, cod, and pollock)	Stable, heavily monitored	Bycatch levels small relative to forage biomass	No concern
HAPC biota	Low bycatch levels of (spp)	Bycatch levels small relative to HAPC biota	No concern
Marine mammals and birds	Very minor direct-take	Safe	No concern
Sensitive non-target species	Likely minor impact	Data limited, likely to be safe	No concern
Fishery concentration in space and time	Low exploitation rate	Little detrimental effect	No concern
Fishery effects on amount of large size target fish	Low exploitation rate	Natural fluctuation	No concern
Fishery contribution to discards and offal production	Stable trend	Improving, but data limited	Possible concern
Fishery effects on age-at-maturity and fecundity	Unknown	NA	Possible concern

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Tables

Table 4.1. Catch (t) of yellowfin sole 1977-2005. Catch for 2005 is the total through September 3, 2005.

		Domestic		
Year	Foreign	JVP	DAP	Total
1977	58,373			58,373
1978	138,433			138,433
1979	99,019			99,019
1980	77,768	9,623		87,391
1981	81,255	16,046		97,301
1982	78,331	17,381		95,712
1983	85,874	22,511		108,385
1984	126,762	32,764		159,526
1985	100,706	126,401		227,107
1986	57,197	151,400		208,597
1987	1,811	179,613	4	181,428
1988		213,323	9,833	223,156
1989		151,501	1,664	153,165
1990		69,677	14,293	83,970
1991			115,842	115,842
1992			149,569	149,569
1993			106,101	106,101
1994			144,544	144,544
1995			124,740	124,740
1996			129,659	129,659
1997			181,389	181,389
1998			101,201	101,201
1999			67,320	67,320
2000			83,850	83,850
2001			63,395	63,395
2002			73,000	73,000
2003			74,418	74,418
2004			69,046	69,046
2005			90,625	90,625

Table 4.2 Estimates of retained and discarded (t) yellowfin sole caught in Bering Sea fisheries.

Year	Retained	Discarded
1987	3	1
1988	7,559	2,274
1989	1,279	385
1990	10,093	4,200
1991	89,054	26,788
1992	103,989	45,580
1993	76,798	26,838
1994	107,629	36,948
1995	96,718	28,022
1996	101,324	28,334
1997	149,570	31,818
1998	80,365	20,836
1999	55,202	12,118
2000	69,788	14,062
2001	54,759	8,635
2002	62,050	10,950
2003	63,732	10,686
2004	57,378	11,668

Table 4.3. Discarded and retained catch of yellowfin sole, by fishery, in 2003 and 2004.

2003			
Target Fishery	Discard	Retained	Grand Total
Atka mackerel	0	1	1
Bottom pollock	0	56	56
Pacific cod	1,348	296	1,643
Mid water pollock	95	44	139
Rockfish	0	0	0
Arrowtooth flounder	0	0	0
Sablefish	0	0	0
Flathead sole	338	1,981	2,319
Rock sole	1,535	4,556	6,090
yellowfin sole	7,370	56,787	64,157
Other species	0	11	11
2003 Total	10,686	63,732	74,418

2004			
Target Fishery			
	Discard	Retained	Grand Total
Atka mackerel	5	2	6.4
Bottom pollock	32	125	156
Pacific cod	1,791	529	2,320
Mid-water pollock	365	250	615
Sablefish	0	0	0
Rockfish	0	0	0
Arrowtooth flounder	1	3	4
Flathead sole	337	1,889	2,226
Rock sole	1,918	1,646	3,564
Yellowfin sole	7,205	52,917	60,122
Greenland turbot	0	1	1
Other flatfish	8	15	23
Other species	7	2	9
2004 Total	11,668	57,378	69,046

Table 4.4. Yellowfin sole fishery catch-at-age numbers (millions), 1977-2004.

YEAR/AGE	7	8	9	10	11	12	13	14	15	16	17+
1977	18.7	42.5	35.7	70.5	48.3	15.8	4.7	2.9	2.2	0.6	0.3
1978	66.8	131.7	113.8	97.8	104.3	38.9	21.6	12.3	4.5	2.7	0.7
1979	20.7	49.4	89.6	82.9	61.3	45.1	22.9	7.1	4.1	1.5	1.3
1980	33.1	19.7	41.3	64.1	60.8	47.7	42.4	23.2	7.4	10.1	4.2
1981	31.1	46.2	41.7	51.7	67.2	70.6	58.4	40.2	18.5	5.7	4.4
1982	27.7	58.9	45.1	42.2	71.5	75.0	39.6	20.1	10.4	2.7	0.5
1983	56.2	39.6	75.9	53.5	53.5	77.1	57.9	32.3	16.5	5.2	2.9
1984	13.2	26.3	34.0	70.5	72.2	94.1	107.8	102.1	56.5	23.6	11.3
1985	36.9	52.1	107.2	106.0	127.9	108.8	108.5	103.9	66.1	29.5	15.4
1986	49.3	40.7	67.6	111.6	82.5	74.7	64.3	40.2	56.5	51.8	28.8
1987	18.2	49.4	33.5	49.3	55.4	59.6	73.4	61.0	26.3	40.1	42.3
1988	29.0	57.5	140.5	40.8	71.7	89.4	53.6	104.1	82.1	34.8	176.9
1989	2.5	33.8	47.0	73.1	29.5	20.5	52.0	32.2	45.3	44.5	172.0
1990	8.8	7.0	52.4	29.2	49.4	20.0	18.4	16.9	17.4	23.2	72.2
1991	9.9	62.5	6.5	116.2	28.8	38.8	7.3	18.5	25.5	16.0	60.3
1992	5.9	24.2	83.8	22.5	123.3	29.9	25.0	13.3	15.2	12.7	71.8
1993	12.2	8.1	11.0	57.4	7.4	74.4	16.3	19.9	9.8	15.1	89.9
1994	21.3	33.7	26.8	26.9	127.5	3.2	90.8	9.7	33.9	13.7	85.6
1995	27.7	46.3	21.0	11.2	13.7	83.3	1.8	103.9	9.7	16.9	69.4
1996	13.1	41.1	43.8	19.4	15.5	25.9	74.2	14.3	75.4	10.6	73.6
1997	19.5	25.2	63.6	40.2	27.4	38.5	29.8	114.7	14.3	63.5	114.4
1998	12.2	13.2	15.7	33.2	28.6	20.0	15.8	16.8	28.2	15.3	100.3
1999	2.77	6.97	7.20	7.59	24.45	18.68	10.29	11.66	14.69	20.14	66.89
2000	1.28	7.72	24.69	10.50	11.66	29.30	25.37	19.02	8.89	20.06	21.35
2001	3.83	7.71	11.48	21.08	15.04	11.35	18.60	15.31	13.81	7.37	9.11
2002	2.88	9.67	12.35	16.72	31.51	14.74	10.74	18.97	13.15	7.62	74.66
2003	2.50	27.41	19.75	11.67	15.21	28.10	11.91	9.12	10.69	11.61	76.36
2004	4.51	6.04	39.73	13.11	9.78	8.89	17.09	6.80	4.72	13.32	78.81

Table 4.5—Yellowfin sole biomass estimates (t) from the annual Bering Sea shelf bottom trawl survey and upper and lower 95% confidence intervals.

	Age					
Year	0-6	7 +	Total	Lower CI		Upper CI
1975	169,500	803,000	972,500	812,300	–	1,132,700
1979	211,500	1,655,000	1,866,500	1,586,000	–	2,147,100
1980	235,900	1,606,500	1,842,400	1,553,200	–	2,131,700
1981	343,200	2,051,500	2,394,700	2,072,900	–	2,716,500
1982	685,700	2,692,100	3,377,800	2,571,000	–	4,184,600
1983	198,000	3,337,300	3,535,300	2,958,100	–	4,112,400
1984	172,800	2,968,400	3,141,200	2,636,800	–	3,645,600
1985	166,200	2,277,500	2,443,700	1,563,400	–	3,324,000
1986	80,200	1,829,700	1,909,900	1,480,700	–	2,339,000
1987	125,500	2,487,600	2,613,100	2,051,800	–	3,174,400
1988	45,600	2,356,800	2,402,400	1,808,400	–	2,996,300
1989	196,900	2,119,400	2,316,300	1,836,700	–	2,795,800
1990	69,600	2,114,200	2,183,800	1,886,200	–	2,479,400
1991	60,000	2,333,300	2,393,300	2,116,000	–	2,670,700
1992	145,900	2,027,000	2,172,900			
1993	188,200	2,277,200	2,465,400	2,151,500	–	2,779,300
1994	142,000	2,468,500	2,610,500	2,266,800	–	2,954,100
1995	213,000	1,796,700	2,009,700	1,724,800	–	2,294,600
1996	161,600	2,137,000	2,298,600	1,749,900	–	2,847,300
1997	239,330	1,924,070	2,163,400	1,907,900	–	2,418,900
1998	150,756	2,178,844	2,329,600	2,033,130	–	2,626,070
1999	57,700	1,246,770	1,306,470	1,118,800	–	1,494,150
2000	73,200	1,508,700	1,581,900	1,382,000	–	1,781,800
2001	135,900	1,727,800	1,863,700	1,605,000	–	2,122,300
2002	83,200	1,933,500	2,016,700	1,740,700	–	2,292,700
2003	2,900	2,236,700	2,239,600	1,822,700	–	2,656,600
2004	191,800	2,338,800	2,530,600	2,147,900	–	2,913,300
2005			2,767,800	2,035,800	–	3,499,800

Table 4.6. Yellowfin sole population numbers-at-age (millions) estimated from the annual bottom trawl surveys, 1982-2004.

Yr/age	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17+
1982	123.9	363.4	742.8	2882.0	3155.6	2408.1	3193.9	1445.1	1556.8	1258.3	1140.6	863.8	531.6	163.8	73.6	90.3
1983	0.0	6.5	142.0	378.6	1659.5	3495.2	1836.1	2388.3	1786.5	1596.7	2079.7	1576.7	771.9	751.4	154.1	114.3
1984	0.0	115.7	494.3	577.0	957.6	1554.7	1765.8	1832.8	1982.2	1759.3	953.2	1018.8	723.4	580.1	310.6	251.4
1985	0.0	43.2	241.9	762.1	1040.2	619.0	1206.2	1353.3	787.5	904.7	846.5	568.1	519.5	448.5	295.5	177.8
1986	0.0	35.2	66.9	310.9	698.3	1297.7	535.4	888.1	787.9	693.1	482.5	507.7	302.1	450.0	212.2	496.4
1987	0.0	6.4	102.2	210.9	1554.7	932.7	1477.6	681.6	650.0	818.8	534.9	552.6	319.4	381.2	392.2	1199.0
1988	1.1	4.0	32.0	782.6	133.7	2997.0	1524.3	1271.8	319.0	500.8	446.7	464.6	821.5	547.6	290.8	1.8
1989	0.0	17.0	45.6	336.8	1848.0	504.1	3244.5	1350.7	979.0	255.0	280.1	503.4	351.8	540.7	267.2	1296.0
1990	0.0	29.1	116.6	220.9	637.7	1947.2	386.5	2400.2	726.2	746.4	141.6	137.6	174.9	102.4	286.1	1003.6
1991	0.0	12.9	229.3	594.0	256.3	718.7	1933.1	207.1	2423.2	535.7	764.6	142.8	196.5	137.6	164.9	1220.9
1992	0.0	12.7	281.7	670.1	854.0	386.5	436.9	1522.3	183.4	1526.2	232.2	467.1	128.0	133.9	203.9	1149.5
1993	0.0	52.8	180.6	610.3	1300.3	828.2	548.0	471.7	2418.5	147.8	1725.1	226.0	223.0	119.5	67.9	1059.6
1994	4.2	75.2	165.8	388.8	944.6	1857.4	1210.8	789.0	475.3	1992.2	25.7	1137.9	89.7	405.7	153.5	434.5
1995	0.0	18.9	321.7	408.2	451.4	1555.6	1192.1	368.7	314.5	99.9	1111.2	33.9	1163.4	153.2	104.5	929.9
1996	0.0	92.3	248.6	1649.8	536.8	513.3	877.8	879.0	555.1	295.4	299.6	1026.4	181.2	1115.8	179.6	1151.4
1997	0.0	37.7	541.6	927.9	1522.9	437.0	422.7	952.2	473.7	307.9	390.5	292.4	1014.1	122.7	578.4	948.9
1998	0.0	58.9	153.2	829.3	989.5	1732.4	418.8	429.9	574.2	685.3	715.0	320.6	333.6	452.9	180.0	1974.4
1999	0.0	8.8	169.1	343.9	402.9	430.5	1307.5	250.5	201.6	555.4	460.8	261.7	126.2	131.3	296.2	1974.4
2000	0.0	24.5	134.8	527.5	417.2	594.2	791.4	1020.8	268.9	384.0	320.1	344.4	278.8	264.3	233.1	1314.5
2001	0.0	1.3	146.4	376.7	1159.0	637.1	750.7	789.3	1174.6	493.1	281.5	406.5	216.7	227.6	302.5	1037.7
2002	0.0	70.4	201.7	326.9	590.9	1500.2	689.1	602.6	473.8	906.0	391.1	225.7	555.0	251.3	297.3	1268.7
2003	0.0	0.0	0.0	5.1	43.5	216.9	1784.3	387.0	773.8	256.2	1197.7	426.4	303.7	436.2	363.7	4524.7
2004	0.0	97.0	302.8	860.9	990.7	642.6	650.7	1830.1	508.4	326.0	417.6	515.0	189.3	58.0	373.7	1525.0

Table 4.7—Mean length and weight at age for yellowfin sole.

	Length		Weight	
Age	cm	in	g	lb
3	11.1	4.4	15.31	0.03
4	14.5	5.7	34.41	0.08
5	17.4	6.9	60.23	1.13
6	19.9	7.8	90.97	0.2
7	22.1	8.7	124.8	0.27
8	24	9.4	160.07	0.35
9	25.6	10.1	195.44	0.43
10	27	10.6	229.92	0.51
11	28.2	11.1	262.79	0.58
12	29.2	11.5	293.59	0.65
13	30.1	11.9	322.06	0.71
14	30.9	12.2	348.09	0.77
15	*31.6*	*12.4*	*371.67*	*0.82*
16	32.1	12.6	392.87	0.87
17	32.6	12.8	411.81	0.91
18	33.1	13	428.65	0.94
19	33.5	13.2	443.55	0.98
20	33.8	13.3	456.69	1.01
21	34	13.4	468.25	1.03
22	34.3	13.5	478.38	1.05
23	34.5	13.6	487.24	1.07
24	34.7	13.7	494.99	1.09
25	34.8	13.7	501.74	1.11
26	34.9	13.7	507.61	1.12

Table 4.8. Female yellowfin sole proportion mature at age from Nichol (1994).

Age	Proportion mature
1	0.00
2	0.00
3	.001
4	.004
5	*.008*
6	.020
7	.046
8	.104
9	.217
10	.397
11	.612
12	.790
13	.899
14	.955
15	.981
16	.992
17	.997
18	1.000
19	1.000
20	1.000

Table 4.9. Key equations used in the population dynamics model.

$N_{t,1} = R_t = R_0 e^{\tau_t}$, $\tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1956-75
$N_{t,1} = R_t = R_\gamma e^{\tau_t}$, $\tau_t \sim N(0,\delta^2{}_R)$	Recruitment 1976-96
$C_{t,a} = \frac{F_{t,a}}{Z_{t,a}}\left(1-e^{-Z_{t,a}}\right)N_{t,a}$	Catch in year *t* for age *a* fish
$N_{t+1,a+1} = N_{t,a}e^{-Z_{t,a}}$	Numbers of fish in year *t+1* at age *a*
$N_{t+1,A} = N_{t,A-1}e^{-Z_{t,A-1}} + N_{t,A}e^{-Z_{t,A}}$	Numbers of fish in the "plus group"
$S_t = \sum N_{t,a}W_{t,a}\phi_a$	Spawning biomass
$Z_{t,a} = F_{t,a} + M$	Total mortality in year *t* at age *a*
$F_{t,a} = s_a\mu^F \exp^{\varepsilon^F{}_t}$, $\varepsilon^F{}_t \sim N(o,\sigma^{2_F})$	Fishing mortality
$s_a = \frac{1}{1+\left(e^{-\alpha+\beta a}\right)}$	Age-specific fishing selectivity
$C_t = \sum C_{t,a}$	Total catch in numbers
$P_{t,a} = {}^{C_{t,a}}\!/\!_{C_t}$	Proportion at age in catch
$SurB_t = q\sum N_{t,a}W_{t,a}v_a$	Survey biomass
$L = \sum_{t,a} m_t p_{t,a} \ln\frac{\hat{p}_{t,a}}{p_{t,a}} + (-0.5)\sum_t\left[\left(\ln\frac{surB_t}{\hat{surB}_t}\,{}^1\!/\!_{\sigma_t}\right)^2 - \ln\sigma_t\right]$	Total log likelihood

Table 4.10. Variables used in the population dynamics model.

Variables	
R_t	Age 1 recruitment in year *t*
R_0	Geometric mean value of age 1 recruitment, 1956-75
R_γ	Geometric mean value of age 1 recruitment, 1976-96
τ_t	Recruitment deviation in year *t*
$N_{t,a}$	Number of fish in year *t* at age *a*
$C_{t,a}$	Catch numbers of fish in year *t* at age *a*
$P_{t,a}$	Proportion of the numbers of fish age *a* in year *t*
C_t	Total catch numbers in year *t*
$W_{t,a}$	Mean body weight (kg) of fish age *a* in year *t*
ϕ_a	Proportion of mature females at age *a*
$F_{t,a}$	Instantaneous annual fishing mortality of age *a* fish in year *t*
M	Instantaneous natural mortality, assumed constant over all ages and years
$Z_{t,a}$	Instantaneous total mortality for age *a* fish in year *t*
s_a	Age-specific fishing gear selectivity
μ^F	Median year-effect of fishing mortality
ε_t^F	The residual year-effect of fishing mortality
ν_a	Age-specific survey selectivity
α	Slope parameter in the logistic selectivity equation
β	Age at 50% selectivity parameter in the logistic selectivity equation
σ_t	Standard error of the survey biomass in year *t*

Table 4.11. Model estimates of yellowfin sole fishing mortality and exploitation rate (catch/total biomass).

Year	FullselectionF	ExploitationRate
1964	0.57	0.15
1965	0.23	0.07
1966	0.35	0.13
1967	0.55	0.21
1968	0.29	0.12
1969	0.63	0.23
1970	0.61	0.20
1971	0.98	0.24
1972	0.33	0.07
1973	0.48	0.10
1974	0.20	0.04
1975	0.23	0.06
1976	0.15	0.04
1977	0.11	0.04
1978	0.21	0.07
1979	0.13	0.05
1980	0.09	0.04
1981	0.09	0.04
1982	0.07	0.04
1983	0.07	0.04
1984	0.10	0.06
1985	0.14	0.09
1986	0.14	0.08
1987	0.12	0.07
1988	0.16	0.09
1989	0.11	0.06
1990	0.06	0.03
1991	0.06	0.04
1992	0.10	0.07
1993	0.07	0.05
1994	0.09	0.06
1995	0.08	0.06
1996	0.09	0.06
1997	0.13	0.09
1998	0.08	0.05
1999	0.06	0.04
2000	0.07	0.05
2001	0.05	0.04
2002	0.06	0.04
2003	0.06	0.04
2004	0.06	0.04
2005		0.05

Table 4.12. Model estimates of yellowfin sole age-specific selectivities for the survey and fishery.

Age	Fishery (1964-2004)	Survey (1982-2004)
1	0.00	0.00
2	0.00	0.01
3	0.00	0.03
4	0.01	0.13
5	0.02	0.40
6	0.04	0.76
7	0.12	0.94
8	0.27	0.99
9	0.51	1.00
10	0.75	1.00
11	0.89	1.00
12	0.96	1.00
13	0.99	1.00
14	0.99	1.00
15	0.99	1.00
16	0.99	1.00
17	0.99	1.00
18	0.99	1.00
19	0.99	1.00
20	0.99	1.00

Table 4.13. Model estimates of yellowfin sole age 2+ total biomass (t) and begin-year female spawning biomass (t) from the 2004 and 2005 stock assessments.

	2005 Assessment		2004 Assessment	
Year	Female Spawning Biomass	Age 2+ Total Biomass	Female Spawning Biomass	Age 2+ Total Biomass
1964	72,219	735,080	71,918	733,966
1965	75,031	739,271	74,665	738,122
1966	100,001	793,203	99,616	791,942
1967	117,105	786,580	116,714	785,181
1968	111,734	712,775	111,323	711,206
1969	122,532	728,388	122,109	726,487
1970	98,922	665,758	98,452	663,428
1971	81,746	662,584	81,233	659,551
1972	53,818	661,096	53,290	657,118
1973	61,836	812,389	61,251	807,119
1974	68,047	960,704	67,337	953,848
1975	93,595	1,174,670	92,683	1,165,990
1976	126,109	1,386,720	124,867	1,376,060
1977	174,138	1,622,290	172,432	1,609,570
1978	235,281	1,860,520	232,970	1,845,720
1979	283,520	2,004,200	280,426	1,987,380
1980	353,351	2,170,300	349,428	2,151,620
1981	436,048	2,323,140	431,244	2,302,750
1982	518,403	2,436,880	512,714	2,414,930
1983	600,970	2,538,280	594,443	2,514,760
1984	674,482	2,614,670	667,189	2,589,550
1985	716,457	2,633,580	708,486	2,606,750
1986	712,607	2,578,120	704,057	2,549,530
1987	695,686	2,531,850	686,691	2,501,510
1988	678,436	2,497,210	669,033	2,465,220
1989	638,154	2,400,990	628,304	2,367,550
1990	636,227	2,364,970	625,821	2,330,280
1991	673,684	2,389,490	662,642	2,353,930
1992	709,189	2,377,820	697,421	2,342,050
1993	712,390	2,288,670	699,873	2,253,670
1994	725,036	2,245,300	711,919	2,212,350
1995	705,083	2,154,950	691,574	2,125,540
1996	681,940	2,079,920	668,278	2,055,270
1997	652,056	1,999,830	638,485	1,979,650
1998	600,290	1,872,510	587,145	1,855,270
1999	581,091	1,827,720	568,876	1,811,370
2000	573,928	1,811,840	563,328	1,792,830
2001	562,268	1,778,980	553,904	1,749,830
2002	558,747	1,758,770	552,885	1,709,920
2003	553,118	1,736,940	549,349	1,658,780
2004	543,656	1,714,080	540,650	1,601,460
2005	538,031	1,705,110		

Table 4.14. Model estimates of yellowfin sole population number at age (billions) for 1954- 2005.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	2.95	4.07	2.13	0.86	0.43	0.37	0.35	0.34	0.33	0.32	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.33	0.34	0.34
1955	1.40	2.62	3.61	1.89	0.76	0.38	0.33	0.31	0.30	0.29	0.28	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.59
1956	0.90	1.24	2.32	3.21	1.68	0.68	0.34	0.29	0.27	0.27	0.26	0.25	0.25	0.25	0.25	0.26	0.26	0.26	0.26	0.77
1957	3.11	0.80	1.10	2.06	2.84	1.49	0.60	0.30	0.26	0.24	0.23	0.23	0.22	0.22	0.22	0.22	0.22	0.22	0.22	0.90
1958	2.31	2.76	0.71	0.98	1.83	2.52	1.32	0.53	0.26	0.22	0.21	0.20	0.20	0.19	0.19	0.19	0.19	0.19	0.19	0.97
1959	1.75	2.04	2.45	0.63	0.87	1.62	2.23	1.16	0.47	0.23	0.19	0.18	0.17	0.17	0.16	0.16	0.16	0.16	0.16	0.99
1960	1.85	1.55	1.81	2.17	0.56	0.77	1.42	1.94	0.98	0.38	0.18	0.15	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.86
1961	1.08	1.64	1.38	1.61	1.92	0.49	0.66	1.19	1.48	0.66	0.22	0.10	0.08	0.07	0.07	0.06	0.06	0.06	0.06	0.50
1962	1.85	0.96	1.45	1.22	1.42	1.67	0.41	0.52	0.79	0.77	0.27	0.08	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.18
1963	0.94	1.64	0.85	1.28	1.07	1.22	1.38	0.31	0.30	0.32	0.21	0.06	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.04
1964	0.88	0.83	1.46	0.75	1.13	0.94	1.06	1.16	0.24	0.21	0.20	0.12	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.02
1965	1.23	0.78	0.74	1.29	0.67	1.00	0.82	0.88	0.88	0.16	0.12	0.11	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.01
1966	1.47	1.09	0.69	0.65	1.14	0.59	0.88	0.70	0.74	0.70	0.12	0.09	0.07	0.04	0.01	0.00	0.00	0.00	0.00	0.01
1967	2.42	1.30	0.97	0.62	0.58	1.01	0.51	0.75	0.57	0.55	0.48	0.08	0.06	0.05	0.03	0.01	0.00	0.00	0.00	0.01
1968	2.63	2.15	1.16	0.86	0.54	0.51	0.87	0.43	0.57	0.38	0.32	0.26	0.04	0.03	0.02	0.01	0.00	0.00	0.00	0.00
1969	2.57	2.34	1.90	1.02	0.76	0.48	0.45	0.75	0.35	0.44	0.27	0.22	0.17	0.03	0.02	0.02	0.01	0.00	0.00	0.00
1970	3.54	2.28	2.07	1.69	0.91	0.67	0.41	0.37	0.56	0.23	0.24	0.14	0.11	0.08	0.01	0.01	0.01	0.01	0.00	0.00
1971	4.31	3.14	2.02	1.83	1.49	0.80	0.58	0.34	0.28	0.36	0.13	0.12	0.07	0.05	0.04	0.01	0.00	0.00	0.00	0.00
1972	4.18	3.82	2.78	1.79	1.62	1.30	0.68	0.46	0.23	0.15	0.16	0.05	0.04	0.02	0.02	0.01	0.00	0.00	0.00	0.00
1973	3.72	3.71	3.39	2.46	1.58	1.43	1.14	0.58	0.37	0.18	0.10	0.10	0.03	0.03	0.02	0.01	0.01	0.00	0.00	0.00
1974	4.07	3.30	3.29	3.00	2.18	1.39	1.24	0.95	0.45	0.26	0.11	0.06	0.06	0.02	0.02	0.01	0.01	0.01	0.00	0.00
1975	4.88	3.61	2.93	2.92	2.66	1.93	1.22	1.07	0.80	0.36	0.20	0.08	0.04	0.04	0.01	0.01	0.01	0.00	0.00	0.00
1976	3.12	4.33	3.20	2.59	2.58	2.35	1.69	1.06	0.90	0.63	0.27	0.14	0.06	0.03	0.03	0.01	0.01	0.00	0.00	0.00
1977	3.65	2.77	3.84	2.84	2.30	2.29	2.07	1.47	0.90	0.74	0.50	0.21	0.11	0.04	0.02	0.02	0.01	0.01	0.00	0.01
1978	2.43	3.24	2.45	3.41	2.52	2.04	2.02	1.81	1.27	0.75	0.60	0.40	0.17	0.09	0.04	0.02	0.02	0.01	0.01	0.01
1979	1.63	2.15	2.87	2.18	3.02	2.22	1.79	1.75	1.52	1.01	0.57	0.44	0.29	0.12	0.06	0.03	0.01	0.01	0.00	0.01
1980	3.04	1.44	1.91	2.54	1.93	2.67	1.96	1.56	1.50	1.26	0.81	0.45	0.35	0.23	0.09	0.05	0.02	0.01	0.01	0.01
1981	2.20	2.69	1.28	1.69	2.26	1.71	2.36	1.72	1.35	1.27	1.05	0.67	0.37	0.28	0.19	0.08	0.04	0.02	0.01	0.02
1982	6.01	1.95	2.39	1.13	1.50	2.00	1.51	2.07	1.49	1.15	1.05	0.86	0.54	0.30	0.23	0.15	0.06	0.03	0.01	0.02
1983	1.03	5.33	1.73	2.12	1.01	1.33	1.77	1.33	1.80	1.28	0.96	0.88	0.71	0.45	0.25	0.19	0.12	0.05	0.03	0.03
1984	4.98	0.92	4.73	1.53	1.88	0.89	1.18	1.55	1.15	1.54	1.07	0.80	0.72	0.59	0.37	0.20	0.16	0.10	0.04	0.04
1985	1.61	4.42	0.81	4.19	1.36	1.66	0.79	1.03	1.34	0.97	1.27	0.87	0.65	0.58	0.47	0.30	0.16	0.13	0.08	0.07
1986	1.29	1.43	3.92	0.72	3.72	1.20	1.47	0.69	0.88	1.11	0.77	0.99	0.67	0.50	0.45	0.36	0.23	0.13	0.10	0.12
1987	1.76	1.14	1.26	3.48	0.64	3.29	1.06	1.28	0.59	0.73	0.89	0.61	0.77	0.52	0.39	0.35	0.28	0.18	0.10	0.17
1988	2.35	1.56	1.01	1.12	3.08	0.57	2.90	0.93	1.10	0.49	0.59	0.70	0.48	0.60	0.41	0.30	0.27	0.22	0.14	0.21
1989	2.35	2.09	1.39	0.90	0.99	2.73	0.50	2.53	0.79	0.90	0.39	0.45	0.54	0.36	0.46	0.31	0.23	0.21	0.17	0.26
1990	1.04	2.09	1.85	1.23	0.80	0.88	2.41	0.44	2.17	0.66	0.73	0.31	0.36	0.43	0.29	0.36	0.25	0.18	0.16	0.34
1991	1.12	0.92	1.85	1.64	1.09	0.71	0.78	2.12	0.38	1.87	0.56	0.62	0.26	0.30	0.36	0.24	0.31	0.21	0.15	0.42
1992	2.79	0.99	0.82	1.64	1.45	0.97	0.62	0.69	1.85	0.33	1.59	0.47	0.52	0.22	0.25	0.30	0.20	0.25	0.17	0.48
1993	1.44	2.48	0.88	0.72	1.45	1.29	0.85	0.55	0.59	1.56	0.27	1.29	0.38	0.41	0.17	0.20	0.24	0.16	0.20	0.52
1994	1.35	1.28	2.20	0.78	0.64	1.29	1.14	0.75	0.48	0.51	1.31	0.23	1.07	0.31	0.34	0.14	0.17	0.20	0.13	0.60
1995	1.25	1.19	1.13	1.95	0.69	0.57	1.14	1.00	0.65	0.40	0.42	1.07	0.18	0.86	0.25	0.28	0.12	0.14	0.16	0.60
1996	3.05	1.11	1.06	1.00	1.73	0.61	0.50	1.00	0.87	0.55	0.34	0.35	0.88	0.15	0.71	0.21	0.23	0.10	0.11	0.62
1997	1.03	2.70	0.98	0.94	0.89	1.53	0.54	0.44	0.87	0.73	0.46	0.27	0.28	0.71	0.12	0.57	0.17	0.18	0.08	0.59
1998	0.92	0.91	2.40	0.87	0.83	0.79	1.35	0.47	0.38	0.72	0.59	0.36	0.21	0.22	0.55	0.09	0.44	0.13	0.14	0.52
1999	1.22	0.81	0.81	2.13	0.77	0.74	0.70	1.18	0.41	0.32	0.60	0.49	0.30	0.18	0.18	0.45	0.08	0.36	0.11	0.54
2000	1.79	1.08	0.72	0.72	1.88	0.68	0.65	0.61	1.04	0.35	0.27	0.51	0.41	0.25	0.15	0.15	0.38	0.06	0.31	0.55
2001	1.92	1.59	0.96	0.64	0.64	1.67	0.60	0.57	0.53	0.89	0.30	0.23	0.42	0.34	0.21	0.12	0.12	0.32	0.05	0.71
2002	2.16	1.70	1.41	0.85	0.57	0.56	1.48	0.53	0.50	0.46	0.76	0.25	0.19	0.35	0.29	0.17	0.10	0.10	0.27	0.64
2003	1.78	1.92	1.51	1.25	0.75	0.50	0.50	1.30	0.47	0.43	0.39	0.63	0.21	0.16	0.29	0.24	0.14	0.09	0.09	0.75
2004	1.96	1.58	1.70	1.34	1.11	0.67	0.45	0.44	1.13	0.40	0.37	0.33	0.53	0.18	0.13	0.25	0.20	0.12	0.07	0.70
2005	1.99	1.74	1.40	1.51	1.19	0.98	0.59	0.39	0.38	0.98	0.34	0.31	0.27	0.44	0.15	0.11	0.21	0.17	0.10	0.65

Table 4.15. Model estimates of yellowfin sole age 5 recruitment (millions) the 2004 and 2005 stock assessments.

Year class	2005 Assessment	2004 Assessment
1959	1,134	1,133
1960	666	665
1961	1,144	1,141
1962	578	576
1963	544	542
1964	759	757
1965	905	901
1966	1,490	1,482
1967	1,618	1,606
1968	1,581	1,569
1969	2,178	2,164
1970	2,661	2,642
1971	2,582	2,562
1972	2,298	2,282
1973	2,515	2,499
1974	3,017	2,997
1975	1,928	1,914
1976	2,255	2,237
1977	1,502	1,489
1978	1,005	996
1979	1,879	1,859
1980	1,358	1,342
1981	3,717	3,673
1982	639	630
1983	3,080	3,039
1984	993	978
1985	796	783
1986	1,089	1,073
1987	1,454	1,437
1988	1,453	1,439
1989	641	656
1990	691	701
1991	1,725	1,785
1992	889	927
1993	832	894
1994	772	790
1995	1,884	1,710
1996	637	611
1997	568	488
1998	752	440
1999	1,108	444
2000	1,185	

Table 4.16. Projections of yellowfin sole female spawning biomass (1,000s t), catch (1,000s t) and full selection fishing mortality rate for seven future harvest scenarios. 2006 ABC is highlighted.

Scenarios 1 and 2
Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2005	504.046	90.625	0.08
2006	484.832	121.417	0.11
2007	454.774	113.522	0.11
2008	426.472	107.851	0.11
2009	404.237	102.711	0.11
2010	391.800	98.350	0.11
2011	387.998	97.476	0.11
2012	387.438	97.633	0.11
2013	388.850	98.635	0.11
2014	391.316	100.183	0.11
2015	395.390	102.132	0.11
2016	398.821	103.186	0.11
2017	402.560	103.997	0.11
2018	406.198	104.769	0.11

Scenario 3
1/2 Maximum ABC harvest permissible

Year	Female spawning biomass	catch	F
2005	504.046	90.625	0.08
2006	493.593	62.253	0.06
2007	487.654	61.119	0.06
2008	480.057	60.639	0.06
2009	474.784	60.928	0.06
2010	475.918	61.935	0.06
2011	483.416	63.302	0.06
2012	492.484	64.549	0.06
2013	502.529	65.830	0.06
2014	512.818	67.162	0.06
2015	524.612	68.639	0.06
2016	534.625	69.868	0.06
2017	544.485	70.991	0.06
2018	553.883	71.992	0.06

Scenario 4
Harvest at average F over the past 5 years

Year	Female spawning biomass	catch	F
2005	504.046	90.625	0.08
2006	496.964	38.970	0.04
2007	500.782	38.980	0.04
2008	502.237	39.328	0.04
2009	505.114	40.088	0.04
2010	513.727	41.251	0.04
2011	528.376	42.613	0.04
2012	544.097	43.856	0.04
2013	560.403	45.085	0.04
2014	576.504	46.313	0.04
2015	593.946	47.618	0.04
2016	608.842	48.718	0.04
2017	623.267	49.728	0.04
2018	636.988	50.646	0.04

Scenario 5
No fishing

Year	Female spawning biomass	catch	F
2005	504.046	0	0
2006	502.514	0	0
2007	522.990	0	0
2008	540.766	0	0
2009	559.166	0	0
2010	582.749	0	0
2011	612.309	0	0
2012	642.470	0	0
2013	672.862	0	0
2014	702.508	0	0
2015	733.469	0	0
2016	760.513	0	0
2017	786.577	0	0
2018	811.550	0	0

Table 4.16—continued.

Scenario 6				Scenario 7			
Determination of whether yellowfin sole are currently overfished		B35=360.500		Determination of whether the stock is approaching an overfished condition		B35=360.500	
Year	Female spawning biomass	catch	F	Year	Female spawning biomass	catch	F
2005	504.046	90.625	0.08	2005	504.046	90.625	0.08
2006	481.416	143.969	0.14	2006	484.832	121.417	0.11
2007	442.426	132.047	0.14	2007	454.774	113.522	0.11
2008	407.257	122.173	0.13	2008	423.493	127.915	0.14
2009	380.959	109.357	0.13	2009	393.997	116.631	0.13
2010	367.004	103.631	0.12	2010	376.661	108.796	0.12
2011	362.243	102.144	0.12	2011	369.268	105.814	0.12
2012	361.123	102.037	0.12	2012	366.060	104.575	0.12
2013	362.156	102.971	0.12	2013	365.510	104.679	0.12
2014	364.344	104.622	0.12	2014	366.538	105.733	0.12
2015	368.013	107.069	0.12	2015	369.406	107.767	0.12
2016	370.978	108.880	0.12	2016	371.806	109.280	0.12
2017	373.941	110.293	0.12	2017	374.404	110.505	0.12
2018	376.560	111.289	0.12	2018	376.795	111.391	0.12

Table 4-17. Yellowfin catch and bycatch from 1992-2004 estimated from a combination of regional office reported catch and observer sampling of the catch.

Species	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Pollock	13,100	15,253	33,200	27,041	22,254	24,100	15,335	8,701	13,425	16,502	14,489	11,396	10,382
Arrowtooth Flounder	366	1,017	1,595	346	820	386	2,382	1,627	1,998	1,845	998	1,125	279
Pacific Cod	8,700	8,723	16,415	13,181	8,684	12,825	10,224	4,380	5,192	6,531	6,259	4,621	3,606
Groundfish, General	7,990	3,847	3,983	2,904	2,565	4,755	3,580	2,524	3,541	3,936	2,678	3,133	1,612
Rock Sole	14,646	7,301	8,097	7,486	12,903	16,693	9,825	10,773	7,345	5,810	10,665	8,419	10,068
Flathead Sole		1,198	2,491	3,929	3,166	3,896	5,328	2,303	2,644	3,231	2,190	2,899	1,102
Sablefish	0	0		0	0	0	0	4	0	0			
Atka Mackerel	1	0			0	0	1	33	0	0	0	17	
Pacific ocean Perch	0	5		0		0	1	12	1	1	1	11	
Rex Sole			1	1		0	20	36	1	2	0		
Flounder, General	16,826	6,615	7,080	11,092	10,372	10,743	6,362	8,812	7,913	4,854	378	214	434
Squid	0		5	0	11	0	2	1	0	0	0	1	
Dover Sole			35										
Thornyhead					0		1						
Shortraker/Rougheye	0				1	0	1	15		1			
Butter Sole			0			3	3		2		7		
Eulachon smelt								0					
Starry Flounder		227	106	16	37	124	35	48	71	82	133		
Northern Rockfish						1	0	0			1		
Dusky Rockfish								0			0		
Yellowfin Sole	136,804	91,931	126,163	108,493	112,818	169,661	90,062	62,941	71,479	54,722	66,178	68,954	65,604
English Sole		1									1		
Unsp.demersal rockfish						12	0						
Greenland Turbot	1	5	5	67	8	4	103	70	24	32	2		1
Alaska Plaice		1,579	2,709	1,130	553	6,351	2,758	2,530	2,299	1,905	10,396	365	5,891
Sculpin, General								215	97	12	1,226		
Skate, General								26	4	21	1,042		
Sharpchin Rockfish								1					
Bocaccio	0												
Rockfish, General	0		0	3	23	0	1	3	4	1		1	3
Octopus								0					
Smelt, general								0	0	0			
Chilipepper		1											
Eels								1	1	0	0		
Lingcod										2			
Jellyfish (unspecified)									127	173	161		
Snails								12	4	0	4		
Sea cucumber								0	56		0		
Korean horsehair crab								0	0	0			
Greenling, General									0				
Shrimp, general								0	0	0	0		

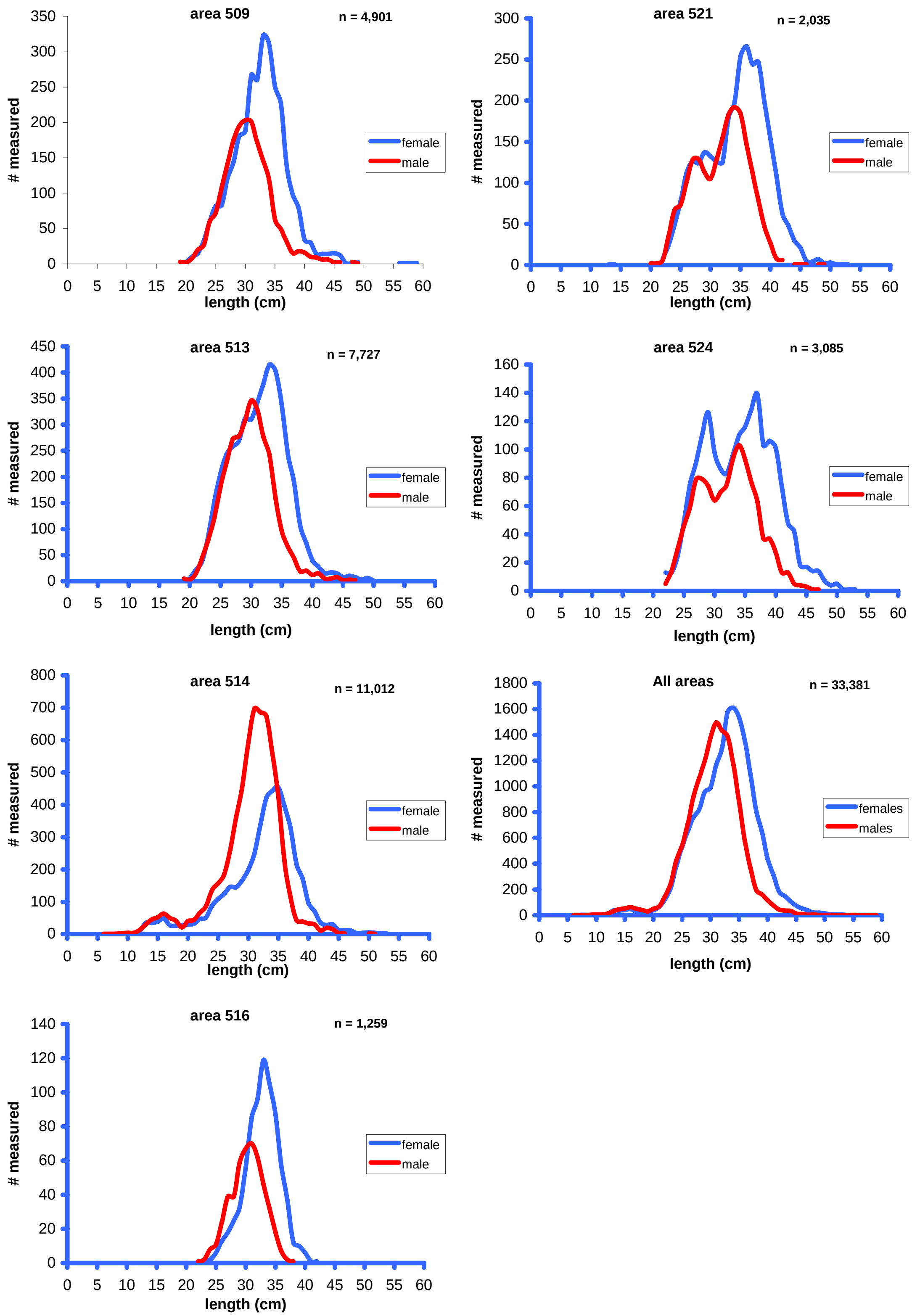


Figure 4.1—Size composition of the yellowfin sole catch in 2005, by subarea and total.

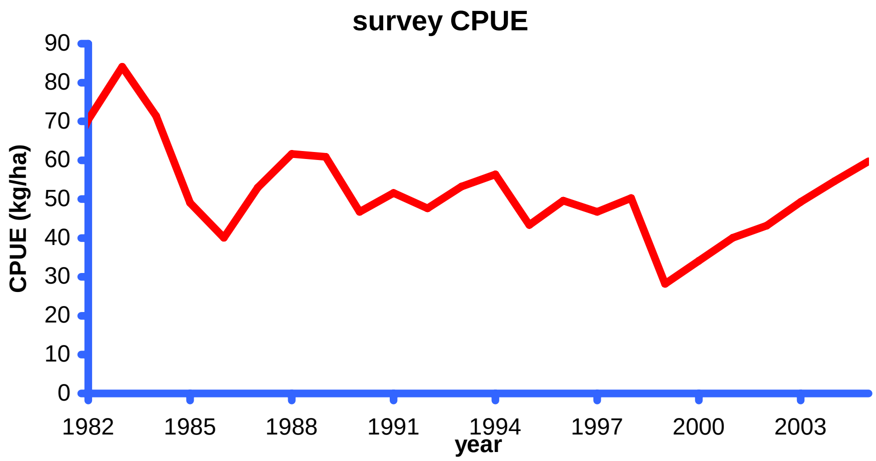


Figure 4.2. Yellowfn sole CPUE (catch per unit effort in kg/ha) from the annual Bering Sea shelf trawl surveys, 1982-2005.

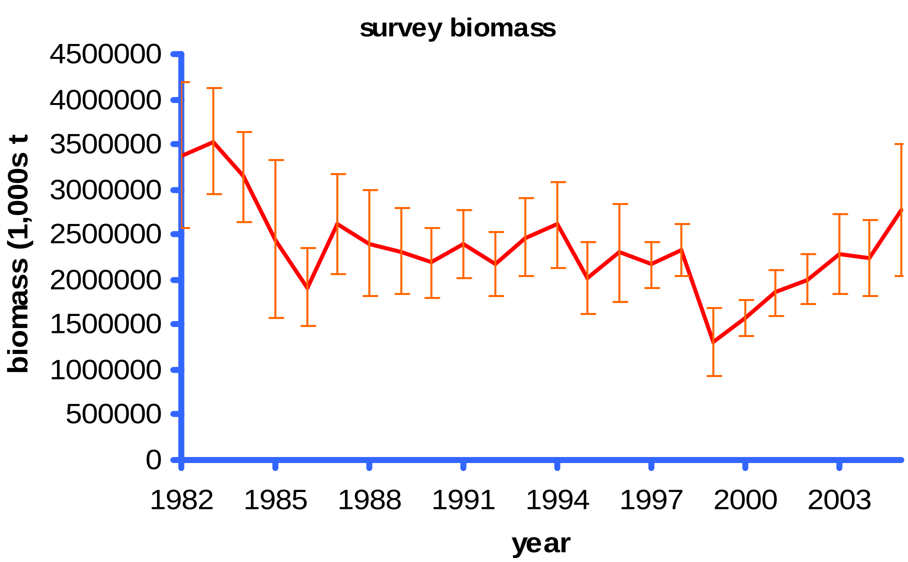


Figure 4.3. Annual bottom trawl survey biomass point-estimates and 95% confidence intervals for yellowfin sole.

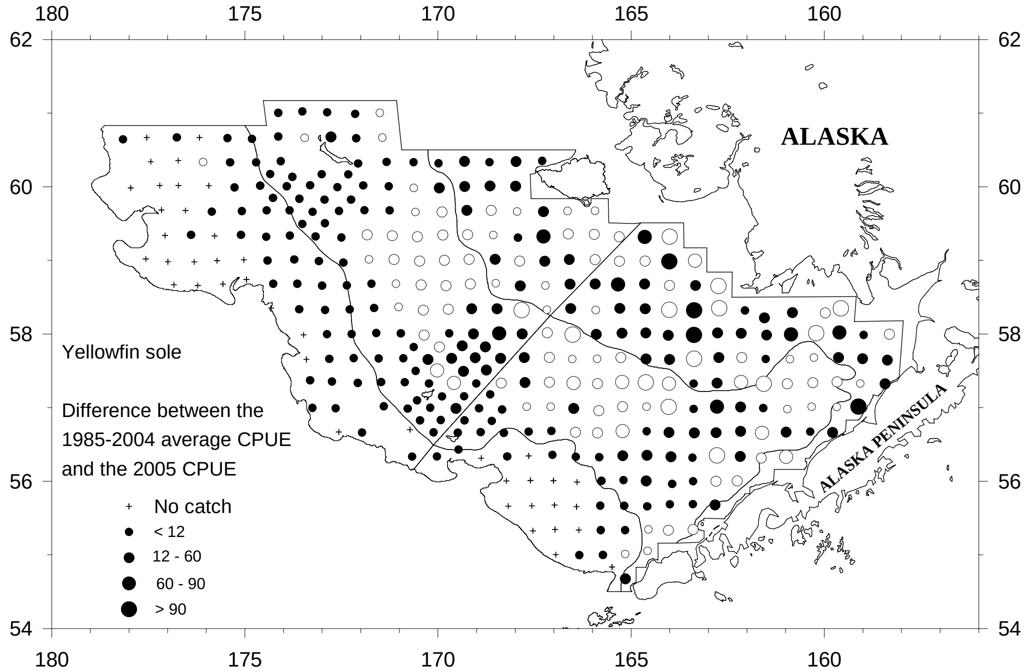


Figure 4.4. Difference between the 1985-2004 average trawl survey CPUE for yellowfin sole and the 2005 survey CPUE. Open circles indicate that the magnitude of the catch was greater in 2005 than the long-term average, closed circles indicate the catch was greater in the long-term average than in 2005.

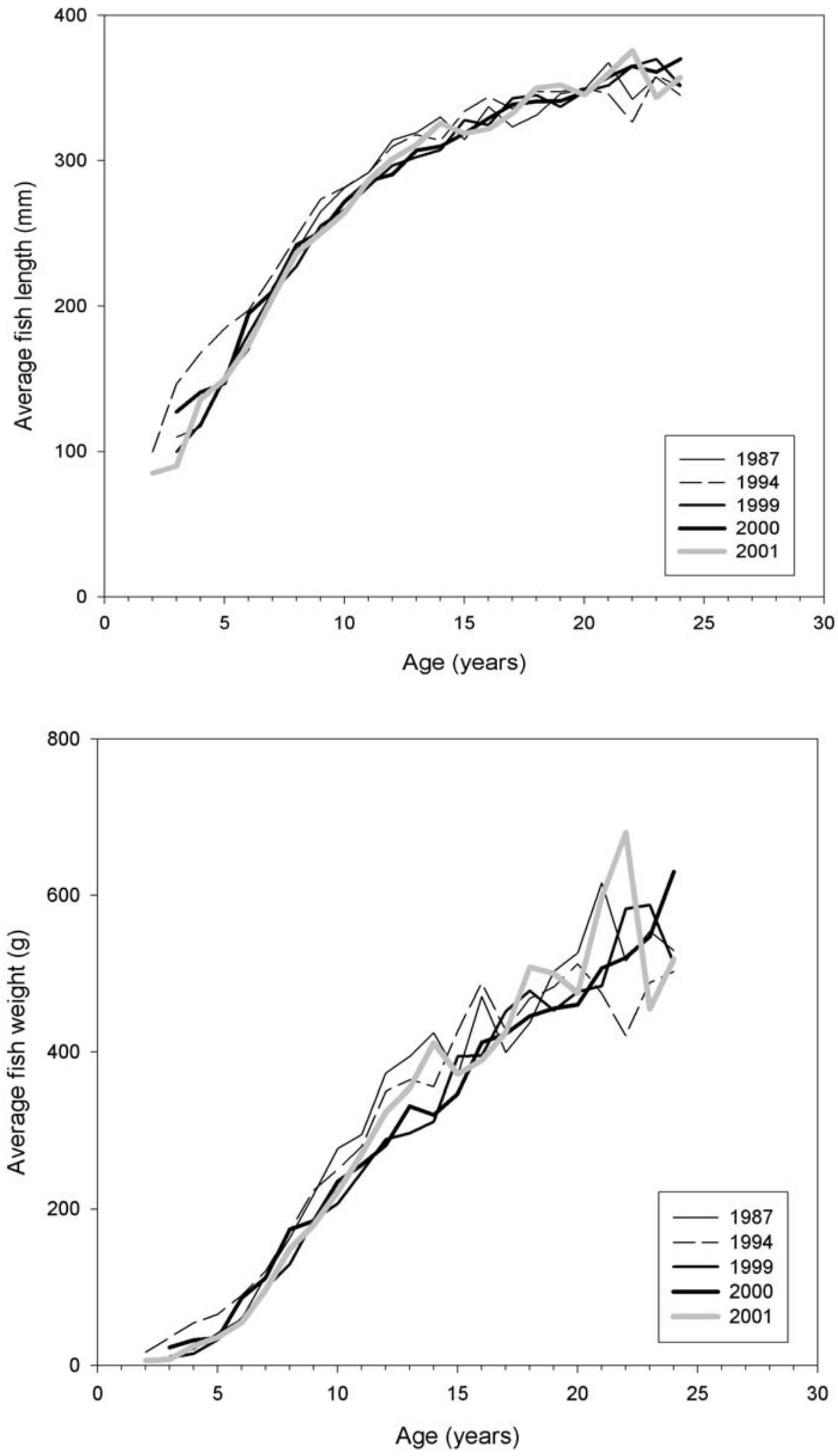


Figure 4.5. Comparison of yellowfin sole length at age (top panel) and weight at age (bottom panel) from biological samples collected in 1987, 1994, 1999, 2000 and 2001.

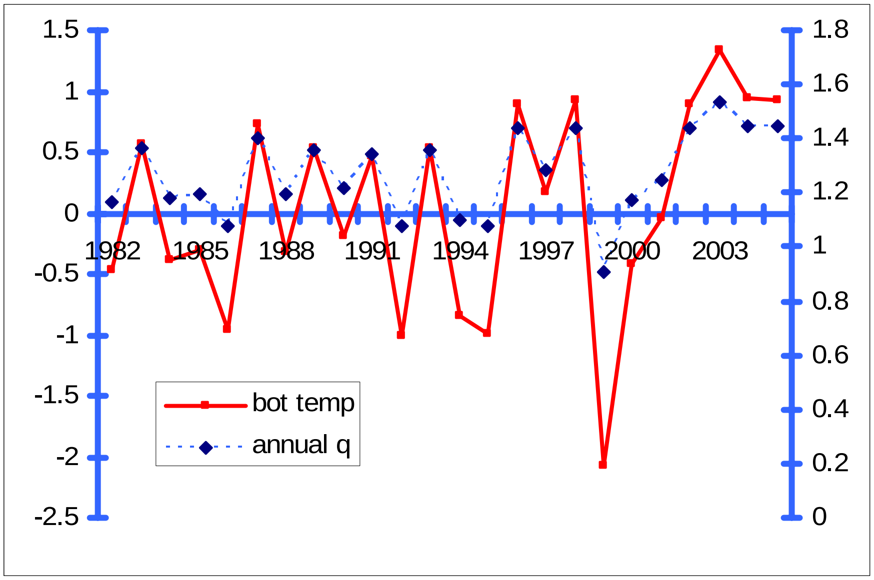


Figure 4.6. Average bottom water temperature from stations less than or equal to 100 m in the Bering Sea trawl survey and the stock assessment model estimate of q for each year 1982-2005.

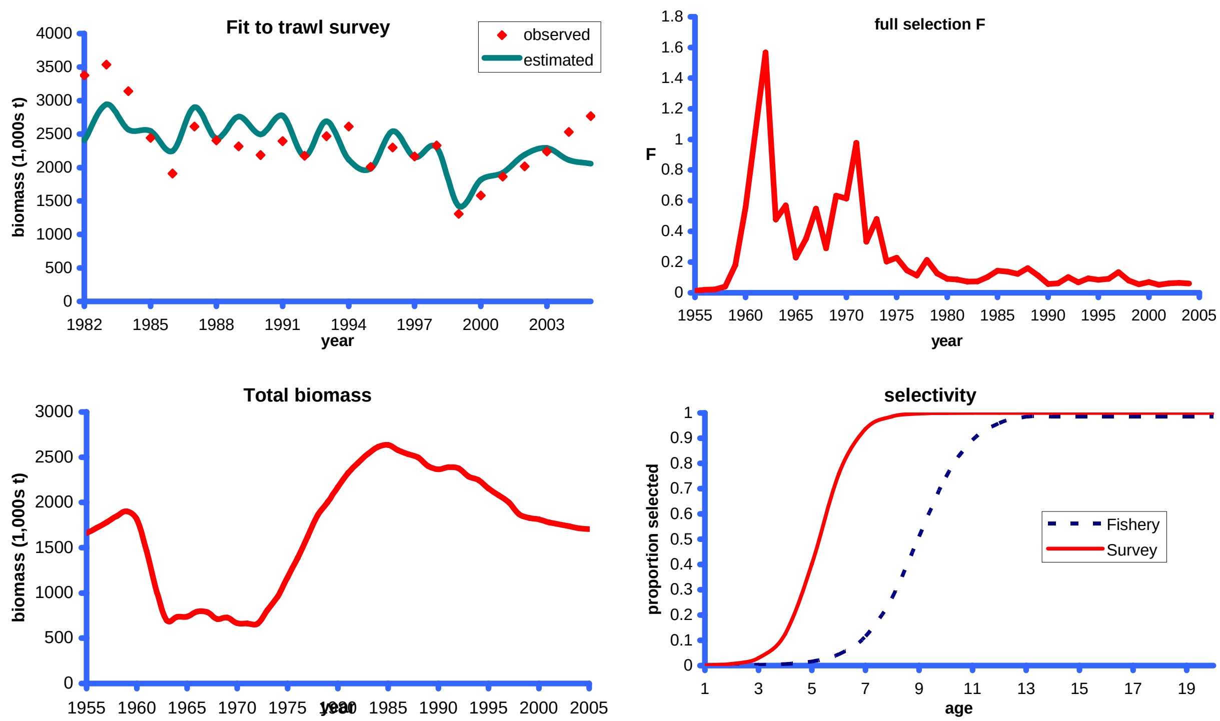


Figure 4.7. Model fit to the survey biomass estimates (top left panel), model estimate of the full selection fishing mortality rate throughout the time-series (top right panel), model estimate of total biomass (bottom left panel) and the model estimate of fishery and survey selectivity (bottom right panel).

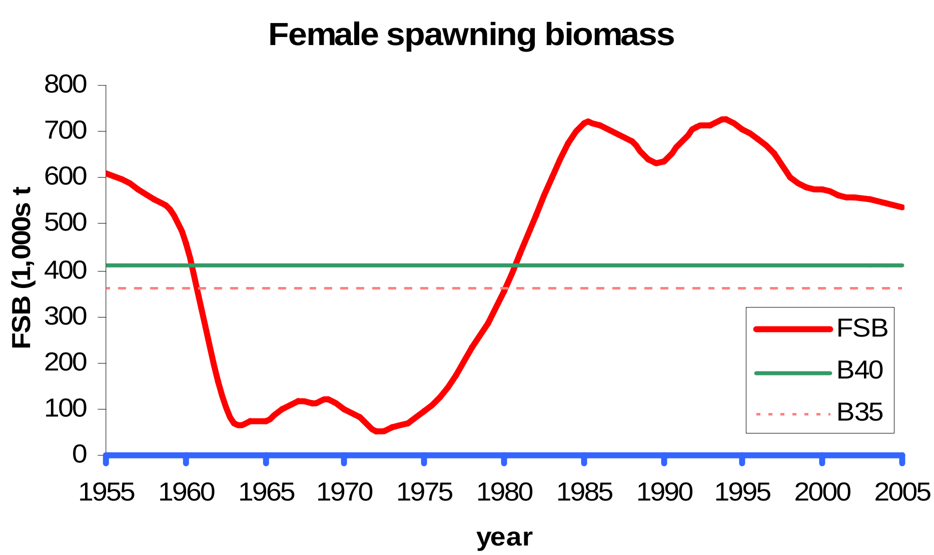


Figure 4.8. Model estimate of yellowfin sole female spawning biomass from 1955-2005 with B40 and B35 levels indicated.

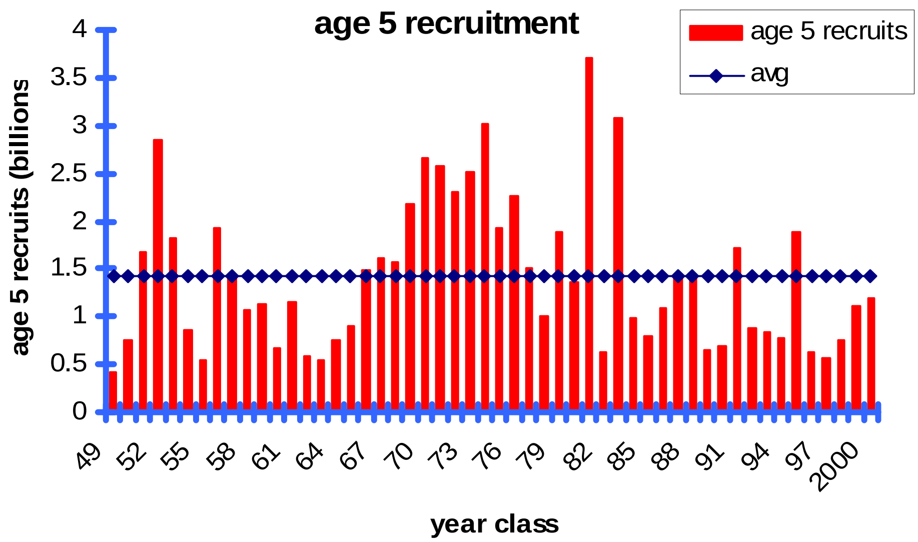


Figure 4.9 Year class strength of age 5 yellowfin sole estimated by the stock assessment model. The dotted line is the average of the estimates from 49 years of recruitment.

All years

Fmsy=0.37

MSY=217,000 t

Bmsy=208,800 t

1978-99

Fmsy=0.22

MSY=150,100

Bmsy=249,800

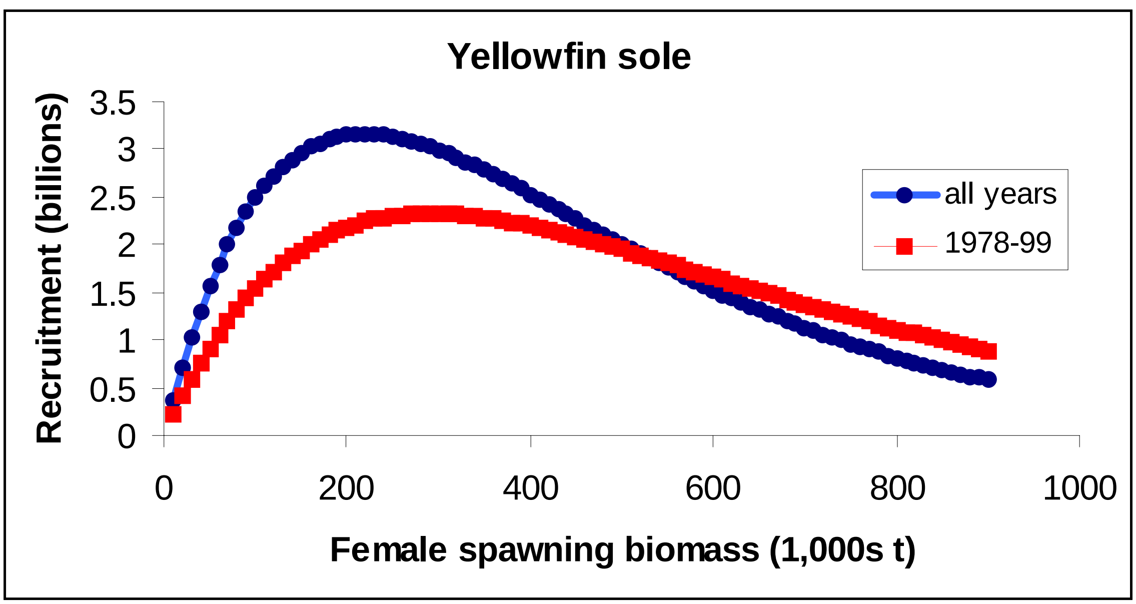


Figure 4.10 Ricker curve fit to yellowfin sole female spawning biomass-age 2 recruitment numbers for two data sets: 1954-99 (all years) and 1978-99.

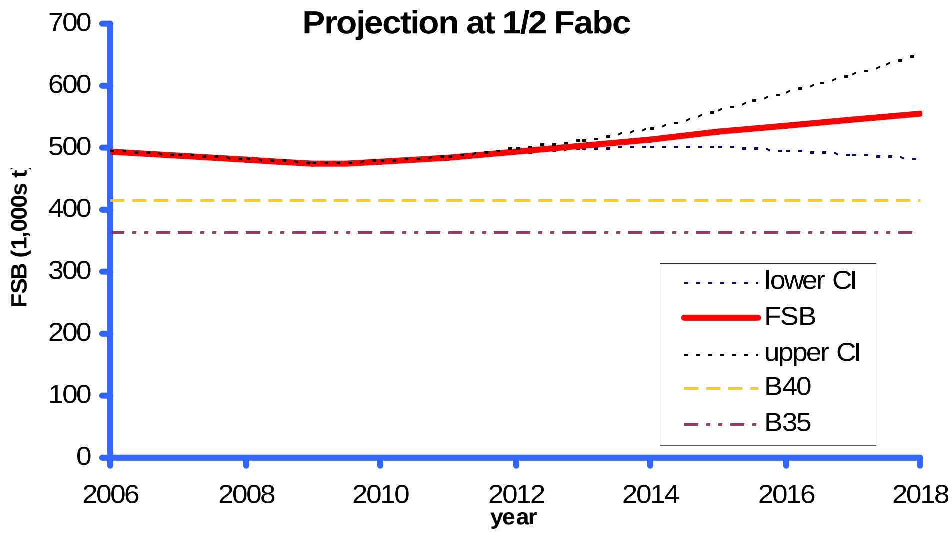


Figure 4.11. Projection of yellowfin sole female spawning biomass (1,000s t) at one half the ABC F level through 2018 with $B_{0.40}$ level indicated.

Appendix

List of figures

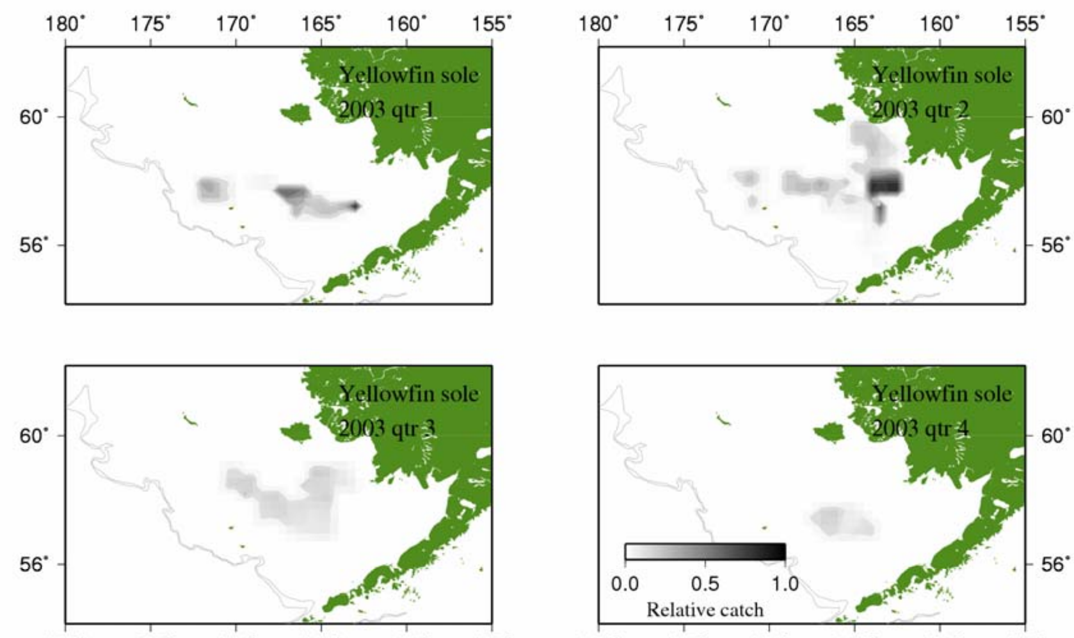
1) 2005 fishery locations by month.

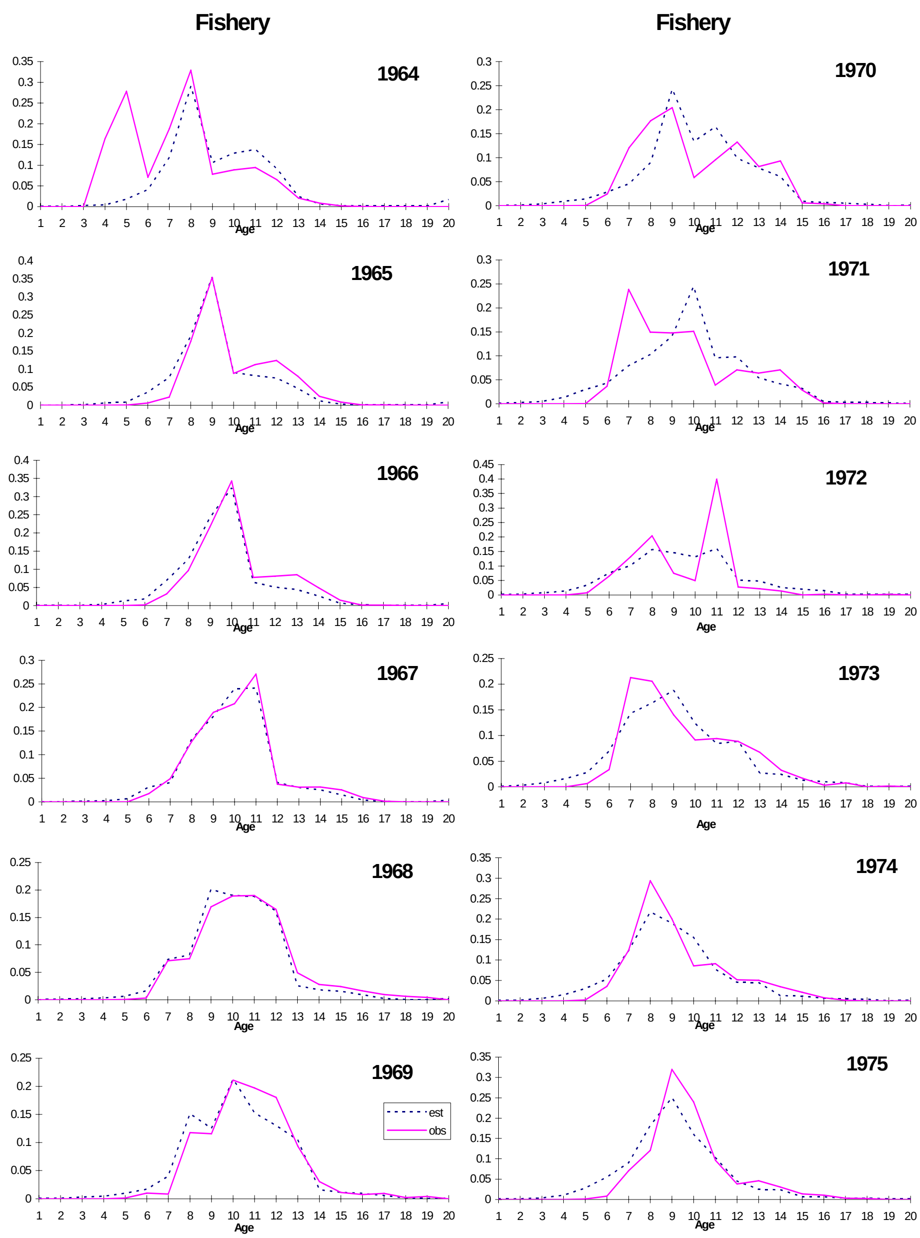
2) Figures showing the fit of the stock assessment model to the time-series of fishery and trawl survey age compositions (survey and fishery observations are the solid lines).

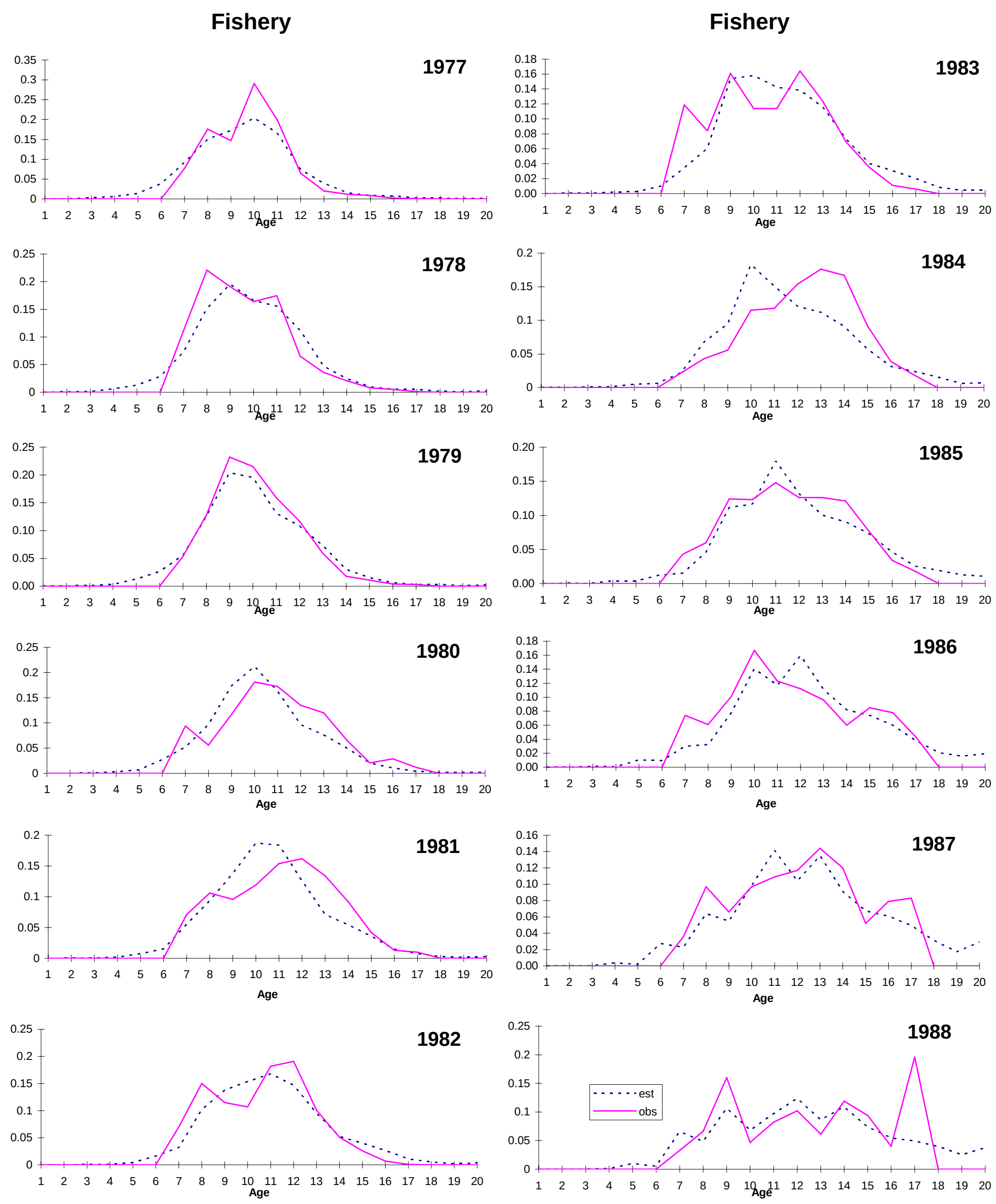
3) Table of yellowfin sole catch from surveys conducted in the eastern Bering Sea and Aleutian Islands area, 1977-2005.

4) Table of number of female spawners (millions) estimated by the stock assessment model for each year.

5) Selected parameter estimates and their standard deviation from the stock assessment model.

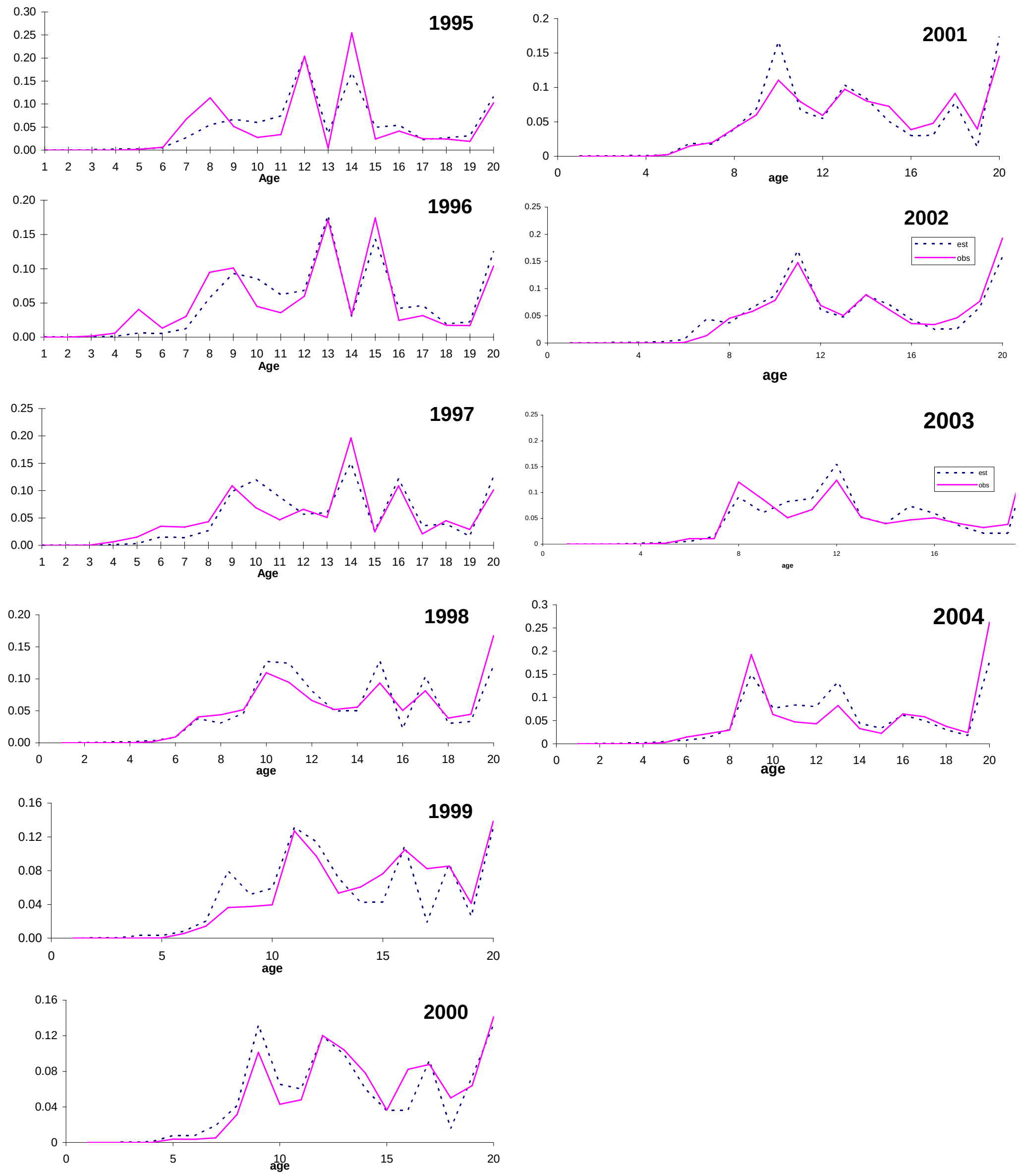


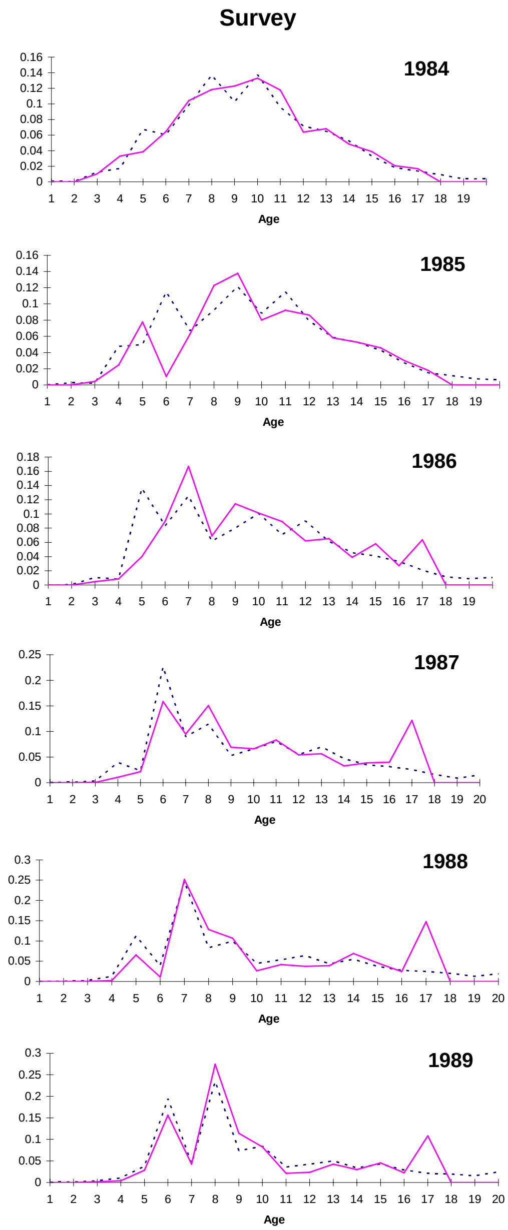

Fishery
Fishery
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
est
obs
Age

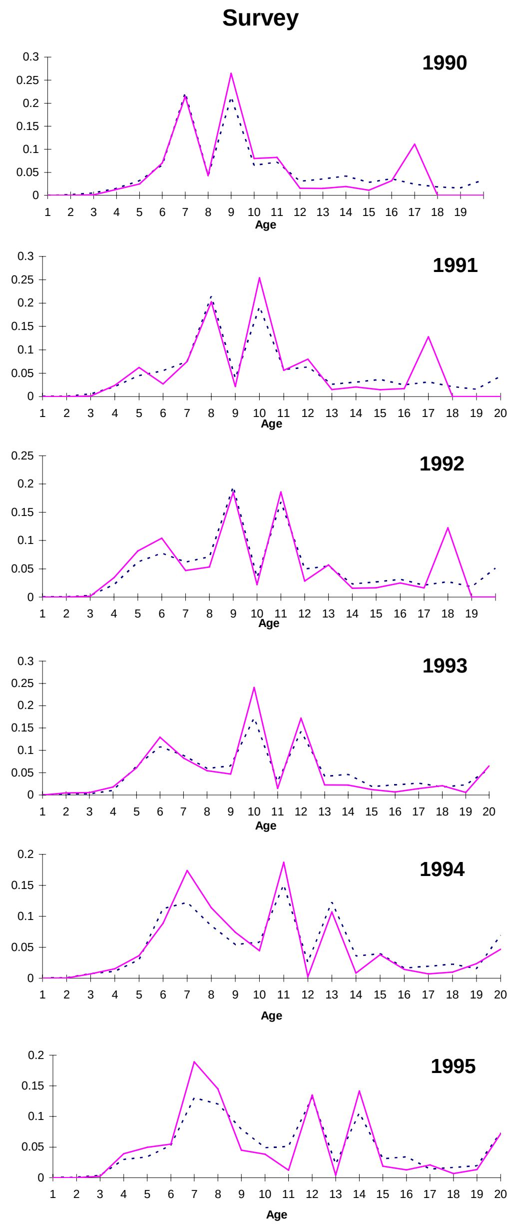


Fishery
Fishery
1977
1983
1978
1984
1979
1985
1980
1986
1981
1987
1982
1988
Age
est
obs

Fishery Fishery




Survey
1984
1985
1986
1987
1988
1989
Age


Survey
1990
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1992
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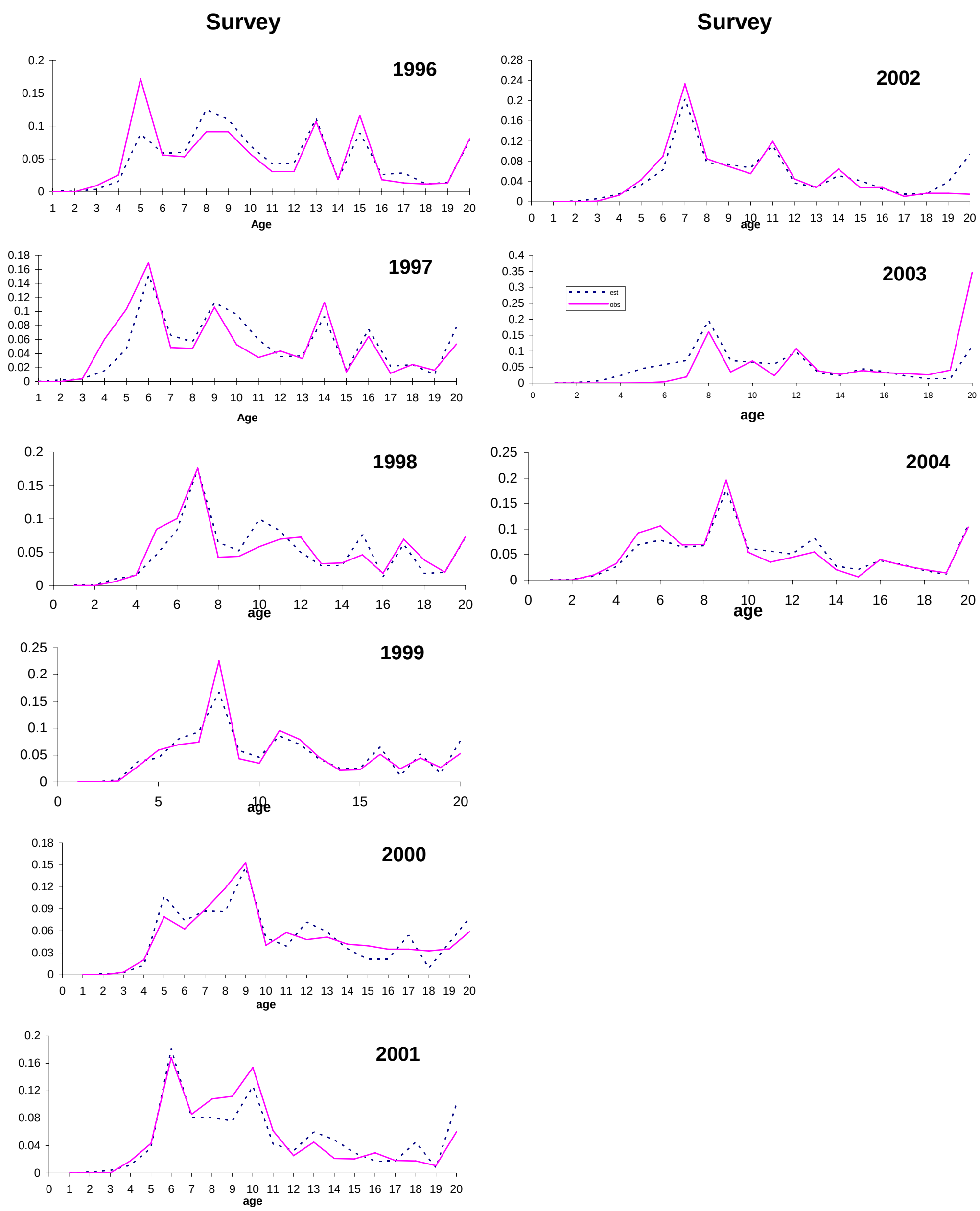
Age


Survey
Survey
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2002
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2003
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age

Total catch of yellowfin sole in Alaska Fisheries Science Center surveys in the Bering Sea.

Year	Research catch (t)
1977	60
1978	71
1979	147
1980	92
1981	74
1982	158
1983	254
1984	218
1985	105
1986	68
1987	92
1988	138
1989	148
1990	129
1991	118
1992	60
1993	95
1994	91
1995	95
1996	72
1997	76
1998	79
1999	61
2000	72
2001	75
2002	76
2003	78
2004	114

Model estimates of yellowfin sole female spawners (millions) from 1954-2005.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1954	0.4	1.2	1.7	1.5	1.8	2.2	8.1	17.8	36.1	64.0	99.6	129.7	148.3	158.1	162.7	165.0	166.0	166.2	167.9	168.5
1955	0.2	0.8	2.9	3.3	3.2	2.3	7.6	16.1	32.8	58.3	86.9	113.1	129.7	138.4	142.6	144.5	145.7	146.2	146.0	295.4
1956	0.1	0.4	1.9	5.6	7.0	4.1	7.8	15.0	29.6	52.9	79.1	98.5	112.8	120.7	124.6	126.4	127.3	128.1	128.2	386.9
1957	0.4	0.2	0.9	3.6	11.9	8.9	13.9	15.4	27.7	47.6	71.3	88.9	97.5	104.1	107.8	109.5	110.4	110.9	111.3	447.6
1958	0.3	0.8	0.6	1.7	7.7	15.1	30.5	27.5	28.4	44.4	64.1	80.1	87.9	90.0	92.9	94.7	95.6	96.2	96.4	485.5
1959	0.2	0.6	1.9	1.1	3.6	9.7	51.6	60.4	50.3	45.1	59.0	70.8	77.9	79.6	78.8	80.1	81.1	81.8	82.0	496.2
1960	0.2	0.5	1.4	3.8	2.3	4.6	33.0	100.7	106.5	74.5	54.0	57.5	60.1	61.4	60.7	59.2	59.8	60.4	60.7	429.3
1961	0.1	0.5	1.1	2.8	8.1	2.9	15.3	61.6	160.3	130.2	67.3	37.6	34.0	32.8	32.3	31.5	30.5	30.8	31.0	251.2
1962	0.2	0.3	1.2	2.1	6.0	10.0	9.6	27.0	85.8	152.2	81.2	30.1	13.8	11.4	10.6	10.3	10.0	9.6	9.7	88.7
1963	0.1	0.5	0.7	2.2	4.5	7.4	32.0	15.9	32.8	62.6	64.6	22.9	6.8	2.8	2.2	2.0	2.0	1.9	1.8	18.6
1964	0.1	0.3	1.2	1.3	4.8	5.7	24.6	60.4	25.8	41.7	60.0	48.3	14.6	4.0	1.6	1.2	1.1	1.1	1.1	11.3
1965	0.2	0.2	0.6	2.3	2.8	6.0	18.9	45.9	95.8	31.4	37.3	41.3	28.2	7.9	2.1	0.8	0.6	0.6	0.6	6.3
1966	0.2	0.3	0.6	1.1	4.8	3.5	20.3	36.6	79.8	138.4	36.2	34.8	33.5	21.2	5.7	1.5	0.6	0.5	0.4	4.8
1967	0.3	0.4	0.8	1.1	2.4	6.1	11.9	38.7	61.6	108.3	145.6	30.3	25.1	22.3	13.7	3.6	0.9	0.4	0.3	3.3
1968	0.3	0.6	0.9	1.5	2.3	3.1	20.2	22.2	61.8	75.6	98.4	102.3	18.1	13.8	11.8	7.2	1.9	0.5	0.2	1.8
1969	0.3	0.7	1.5	1.8	3.2	2.9	10.3	38.9	38.0	86.6	83.4	87.1	78.2	12.8	9.4	8.0	4.8	1.3	0.3	1.4
1970	0.5	0.7	1.7	3.0	3.8	4.0	9.6	19.1	60.7	44.7	73.8	54.2	47.9	39.5	6.3	4.5	3.8	2.3	0.6	0.8
1971	0.6	0.9	1.6	3.2	6.3	4.8	13.3	17.8	29.9	72.1	38.7	48.8	30.4	24.6	19.6	3.1	2.2	1.9	1.1	0.7
1972	0.5	1.2	2.2	3.1	6.8	7.8	15.6	23.7	25.3	29.5	47.5	18.5	19.3	10.9	8.6	6.7	1.0	0.8	0.6	0.6
1973	0.5	1.1	2.7	4.3	6.6	8.6	26.3	30.0	40.1	34.7	31.5	40.4	13.6	13.1	7.2	5.5	4.3	0.7	0.5	0.8
1974	0.5	1.0	2.6	5.3	9.2	8.4	28.7	49.6	48.7	50.9	33.1	23.5	25.7	8.0	7.4	4.0	3.1	2.4	0.4	0.7
1975	0.6	1.1	2.3	5.1	11.2	11.6	28.3	55.8	86.8	71.3	59.9	31.6	19.5	19.9	5.9	5.5	2.9	2.2	1.7	0.8
1976	0.4	1.3	2.5	4.5	10.8	14.1	39.1	54.9	97.0	125.5	82.2	55.9	25.7	14.7	14.4	4.3	3.9	2.1	1.6	1.8
1977	0.5	0.8	3.1	5.0	9.7	13.7	48.0	76.6	97.6	146.3	153.9	82.6	49.1	20.9	11.6	11.2	3.3	3.0	1.6	2.6
1978	0.3	1.0	2.0	6.0	10.6	12.2	46.7	94.2	137.5	149.6	183.9	159.4	74.9	41.4	17.1	9.3	9.0	2.6	2.4	3.3
1979	0.2	0.7	2.3	3.8	12.7	13.3	41.4	90.6	164.6	200.1	174.4	173.9	131.0	57.1	30.5	12.4	6.7	6.5	1.9	4.1
1980	0.4	0.4	1.5	4.5	8.1	16.0	45.4	81.2	162.1	250.6	249.1	178.5	155.6	109.0	45.9	24.2	9.8	5.3	5.1	4.7
1981	0.3	0.8	1.0	3.0	9.5	10.2	54.6	89.4	146.5	251.2	320.1	262.9	165.0	133.9	90.7	37.7	19.7	7.9	4.3	7.9
1982	0.8	0.6	1.9	2.0	6.3	12.0	34.9	107.6	161.6	227.7	322.3	339.6	244.4	142.9	112.1	74.8	30.9	16.1	6.5	9.9
1983	0.1	1.6	1.4	3.7	4.2	8.0	40.9	68.9	195.2	252.8	295.0	345.8	319.6	214.3	121.1	93.6	62.0	25.5	13.3	13.5
1984	0.7	0.3	3.8	2.7	7.9	5.3	27.2	80.7	125.0	305.2	327.3	316.3	325.2	280.1	181.6	101.0	77.6	51.3	21.1	22.1
1985	0.2	1.3	0.7	7.3	5.7	10.0	18.2	53.6	145.2	192.8	387.1	342.4	289.7	277.3	230.9	147.4	81.5	62.5	41.2	34.7
1986	0.2	0.4	3.1	1.3	15.6	7.2	33.9	35.6	95.3	219.1	236.9	389.9	301.1	237.0	219.3	179.8	114.0	62.9	48.1	58.4
1987	0.2	0.3	1.0	6.1	2.7	19.7	24.5	66.5	63.6	144.4	270.7	240.1	345.3	248.0	188.7	171.9	140.1	88.7	48.8	82.6
1988	0.3	0.5	0.8	2.0	12.9	3.4	67.2	48.1	119.0	96.9	180.1	277.6	215.3	288.1	200.1	149.9	135.7	110.3	69.7	103.2
1989	0.3	0.6	1.1	1.6	4.2	16.4	11.5	131.2	85.3	178.1	117.6	178.9	240.4	173.3	224.3	153.3	114.1	103.2	83.6	131.0
1990	0.1	0.6	1.5	2.2	3.3	5.3	55.7	22.6	235.6	130.8	224.1	121.9	162.2	202.9	141.4	180.2	122.4	91.0	81.9	170.5
1991	0.2	0.3	1.5	2.9	4.6	4.2	18.0	110.1	41.3	371.7	171.5	244.1	116.6	144.6	174.9	120.0	151.9	103.0	76.3	211.8
1992	0.4	0.3	0.7	2.9	6.1	5.8	14.5	35.6	200.2	64.9	485.3	185.8	232.1	103.3	123.9	147.5	100.6	127.1	85.9	240.3
1993	0.2	0.7	0.7	1.3	6.1	7.7	19.7	28.4	64.0	308.7	82.3	507.7	170.1	197.9	85.2	100.5	119.0	81.0	102.0	261.9
1994	0.2	0.4	1.7	1.4	2.7	7.7	26.4	39.0	51.6	100.4	401.5	88.7	480.2	150.0	168.6	71.5	83.8	99.0	67.2	301.9
1995	0.2	0.4	0.9	3.4	2.9	3.4	26.3	51.9	70.3	79.9	128.1	422.9	81.9	412.6	124.6	137.9	58.1	68.0	80.1	298.5
1996	0.4	0.3	0.8	1.8	7.3	3.7	11.6	51.9	93.9	109.3	102.6	136.1	393.7	71.0	345.9	102.8	113.1	47.6	55.5	309.1
1997	0.1	0.8	0.8	1.6	3.7	9.2	12.5	22.9	93.7	145.5	139.7	108.4	125.9	339.2	59.1	283.7	83.8	92.0	38.6	295.6
1998	0.1	0.3	1.9	1.5	3.5	4.7	31.2	24.5	40.8	142.1	180.0	141.9	96.2	103.9	270.7	46.5	221.5	65.3	71.5	259.7
1999	0.2	0.2	0.6	3.7	3.2	4.4	16.1	61.5	44.4	63.6	183.0	191.9	132.6	83.7	87.5	224.3	38.3	182.1	53.5	271.4
2000	0.2	0.3	0.6	1.3	7.9	4.1	15.1	31.9	112.1	70.1	83.5	199.5	183.7	118.3	72.2	74.3	189.4	32.2	153.0	272.9
2001	0.3	0.5	0.8	1.1	2.7	10.0	14.0	29.8	57.8	175.7	91.0	89.9	188.4	161.6	100.7	60.5	61.8	157.3	26.7	352.7
2002	0.3	0.5	1.1	1.5	2.4	3.4	34.2	27.7	54.4	91.4	230.9	99.4	86.2	168.4	139.7	85.7	51.2	52.2	132.4	319.4
2003	0.2	0.6	1.2	2.2	3.2	3.0	11.6	67.6	50.4	85.6	119.4	250.3	94.6	76.5	144.4	117.9	71.9	42.8	43.6	377.1
2004	0.3	0.5	1.4	2.3	4.7	4.0	10.3	22.8	122.9	79.2	111.6	129.1	237.6	83.7	65.4	121.6	98.7	60.0	35.7	350.3
2005	0.3	0.5	1.1	2.6	5.0	5.9	13.6	20.4	41.6	193.5	103.5	121.1	123.1	211.1	71.9	55.3	102.2	82.8	50.2	322.7

Selected parameter estimates and their standard deviation from the stock assessment model.

	parameter	value	std dev		parameter	value	std dev
	alpha (q estimation)	-0.22	0.05	1971	total biomass	662.58	15.47
	beta (q estimation)	0.15	0.03	1972	total biomass	661.10	16.76
	mean_log_rec	0.69	0.11	1973	total biomass	812.39	20.16
	sel_slope_fsh	1.04	0.02	1974	total biomass	960.70	23.95
	sel_slope_srv	1.55	0.07	1975	total biomass	1174.70	28.35
	sel50_fsh	8.96	0.07	1976	total biomass	1386.70	33.00
	sel50_srv	5.26	0.06	1977	total biomass	1622.30	37.82
	F40	0.11	0.00127	1978	total biomass	1860.50	42.63
	F35	0.14	0.00160	1979	total biomass	2004.20	46.98
	F30	0.16	0.00206	1980	total biomass	2170.30	51.21
	Ricker S/R logalpha	-3.26	0.17	1981	total biomass	2323.10	55.07
	Ricker S/R logbeta	-5.46	0.09	1982	total biomass	2436.90	58.39
	Fmsy	0.36	0.05	1983	total biomass	2538.30	61.46
	logFmsy	-1.01	0.13	1984	total biomass	2614.70	64.33
	msy	227.74	27.43	1985	total biomass	2633.60	67.02
	Bmsy	223.45	16.18	1986	total biomass	2578.10	69.38
1954	total biomass	1623.10	140.05	1987	total biomass	2531.90	71.83
1955	total biomass	1661.00	122.35	1988	total biomass	2497.20	74.26
1956	total biomass	1719.50	102.23	1989	total biomass	2401.00	76.16
1957	total biomass	1780.10	81.93	1990	total biomass	2365.00	78.35
1958	total biomass	1848.50	63.64	1991	total biomass	2389.50	80.57
1959	total biomass	1901.10	49.41	1992	total biomass	2377.80	82.35
1960	total biomass	1814.30	40.32	1993	total biomass	2288.70	83.70
1961	total biomass	1457.30	32.22	1994	total biomass	2245.30	85.26
1962	total biomass	1006.90	21.55	1995	total biomass	2154.90	86.52
1963	total biomass	697.72	12.90	1996	total biomass	2079.90	87.90
1964	total biomass	735.08	13.47	1997	total biomass	1999.80	89.41
1965	total biomass	739.27	13.66	1998	total biomass	1872.50	90.90
1966	total biomass	793.20	14.46	1999	total biomass	1827.70	93.07
1967	total biomass	786.58	14.73	2000	total biomass	1811.80	95.23
1968	total biomass	712.77	14.02	2001	total biomass	1779.00	97.57
1969	total biomass	728.39	14.73	2002	total biomass	1758.80	99.70
1970	total biomass	665.76	14.45	2003	total biomass	1736.90	102.86
				2004	total biomass	1714.10	107.52
				2005	total biomass	1705.10	115.58

Yellowfin sole TAC and ABC levels, 1980-2005

Year	TAC	ABC
1980	117,000	169,000
1981	117,000	214,500
1982	117,000	214,500
1983	117,000	214,500
1984	230,000	310,000
1985	229,900	310,000
1986	209,500	230,000
1987	187,000	187,000
1988	254,000	254,000
1989	182,675	241,000
1990	207,650	278,900
1991	135,000	250,600
1992	235,000	372,000
1993	220,000	238,000
1994	150,325	230,000
1995	190,000	277,000
1996	200,000	278,000
1997	230,000	233,000
1998	220,000	220,000
1999	207,980	212,000
2000	123,262	191,000
2001	113,000	176,000
2002	86,000	115,000
2003	83,750	114,000
2004	86,075	114,000
2005	90,686	124,000

posterior distributions